REMTECH

RTR 174-01

EXTERNAL TANK AEROTHERMAL DESIGN CRITERIA VERIFICATION VOLUME I

May 1990

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Contract:

NAS8-36946

For:

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FOREWORD

This final report documents the ET thermal environment generation work performed under the ET Aerothermal Design Criteria Verification study (NAS8-36946). The work was performed for the Thermal Environments Branch (ED-33) of the George C. Marshall Space Flight Center (MSFC).

During the course of the work significant results and progress were documented in the progress reports submitted each month. The purpose of this report is to summarize the thermal environment generation methodology and to present a comparison with the Rockwell IVBC-3 environments. The report is presented in two Volumes. Volume I contains the methodology and environment summaries. Volume II contains the plotted timewise environments comparing the REMTECH results to the Rockwell IVBC-3 results.

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Nomenclature

Symbol	Decription
f	Wind tunnel to flight scaling factor $f = \frac{(Hi/Hu)_{\text{Flight}}}{(Hi/Hu)_{\text{Tunnel}}}$
H	Heat transfer coefficient, BTU/Ft^{2}sec °R
HCNV	Cold wall heat transfer coefficient (HW = 110 BTU/lbm°R), lbm/ft^{2}sec (see Table 12)
Hi/Hu	Interference to undisturbed heat transfer amplification factor
HR	Enthalpy based on boundary layer recovery temperature, BTU/lbm°R
H_{u_o}	Clean skin undisturbed heat transfer coefficient for $\alpha_{\text{effective}} =$ 0 deg, BTU/ft^{2}sec°R.
INTRF	Interference to undisturbed heat transfer amplification factor, H_i/H_u. Tabulated data (see Table 12).
M, MACH, M_∞	Freestream Mach number
M_L	Mach number based on local conditions
N_L	Mangler transformation factor for a laminar boundary layer, see Figure 11 and Tables 7 - 9.
N_T	Mangler transformation factor for a laminar boundary layer, see Figure 11 and Tables 7 - 9.
OT	Shuttle ascent configuration consisting of the orbiter and external tank.
OTS	Shuttle ascent configuration consisting of the orbiter, external tank and two solid rocket boosters.
P_s	Local static pressure, psf
P_∞	Freestream static pressure, psf
Q_{DOT}	Cold wall heating rate along the ascent trajectory, BTU/ft^{2}sec.
Q_{LOAD}	Integrated heat load along the ascent trajectory, BTU/ft^2
r	Recovery factor, see Section 4.2.2
RF	Roughness factor, see Section 4.3.2, Tables 6 - 9
Re_{inf}	Freestream unit Reynolds number, $\frac{1}{Ft}$.
Re_θ	Reynolds number based on the boundary layer momentum thickness.
S	Boundary layer running length, ft., see Section 4.2.2.3

Symbol	Decription
T_∞	Freestream static temperature, °R
WF	Waviness factor defined in Section 4.3.3.
X_T	External tank axial coordinate measured along the centerline of the tank, ft.
Greek	
α	Angle of attack in the body axis system, nominal design trajectory, deg.
α_{eff}	Effective angle of attack defined in Section 4.2.1
α^-	Angle of attack with negative dispersions, deg., (see Fig. 8, Table 5)
α^+	Angle of attack with positive dispersions, deg., (see Fig. 8, Table 5)
β	Angle of sideslip in the body axis system, nominal design trajectory, deg.
β^-	Angle of sideslip with negative dispersions, deg., See Fig. 8, Table 5.
β^+	Angle of sideslip with positive dispersions, deg., See Fig. 8. Table 5.
Δ_α	Angle of attack dispersions, deg., see Table 5
Δ_β	Angle of slipslip dispersions, deg., see Table 5
θ_s	Shock angle for a 39.38 deg. cone, deg., defined in Fig. 9
θ_T	External tank circumferential coordinate, deg., see Fig. 6
ρ_∞	Freestream density, lbm/ft^3

Section 1
INTRODUCTION

The Thermal Protection System (TPS) for the Space Shuttle External Tank (ET) is designed to maintain primary structure, subsystem components, and propellants within design temperature limits. The three thermal protection materials currently used to protect the outer surfaces of the ET are Foam Insulation (several types), Ablator SLA-561, and Ablator MA-25. The type, location, and thicknesses of these materials are primarily dictated by the level of the aerodynamic heating environments during ascent flight (lift-off to MECO). The ascent design thermal environments for the ET were generated by Rockwell International (RI). This set, referred to as the IVBC-3 set, [1] is composed of the time dependent definition of flow field and heating data for 679 surface locations on the ET skin and protuberances. These environments reflect the most up to date wind tunnel results (IH-97, [2]) as well as flight heating measurements from STS 1-7.

The objective of this study was to produce an independent set of ascent environments which would serve as a check on the Rockwell IVBC-3 environments and provide an independent reevaluation of the thermal design criteria for the External Tank. Design heating rates and loads were calculated at 367 acreage body point locations. Ascent flight regimes covered were lift-off, first stage ascent, SRB staging and second stage ascent through ET separation.

The purpose of this report is to document these results, briefly describe the methodology used and present the environments along with a comparison with the Rockwell IVBC-3 counterpart. This report is presented in two Volumes. Volume I contains the methodology and environment summaries. Volume II contains the plotted timewise environments comparing the REMTECH results to the RI IVBC-3 results.

Section 2
BODY POINT DESCRIPTION

Ascent heating environments were calculated at acreage body point locations. These locations were broken into four categories: (a) The nose spikes and nose cone ($327.25 \leq X_T \leq 371.0$), (b) The LO_2 tank ($371.0 \leq X_T \leq 852.80$), (c) The intertank ($852.80 \leq X_T \leq 1125.15$), and (d) The LH_2 tank ($1125.15 \leq X_T \leq 2173.02$). Body point locations for these components are shown in Figs. 1 through 5 respectively. The individual X_T, θ_T locations are defined in Tables 1 through 5. An over all sketch of the light weight, External Tank configuration presented in Fig. 6.

Section 3
TRAJECTORY

The ascent aeroheating environments were generated using the 1980 BRM 3A 3σ Dispersed Light Weight Tank (LWT) Design Trajectory. It is based on a December launch from the Vandenberg Western Test Range and incorporates a right quartering head wind with α and β dispersions. The trajectory data consists of the altitude, velocity, angle of attack (α), angle of side slip (β), ambient density and temperature, and the $\Delta\alpha$ and $\Delta\beta$ system dispersions from lift-off through ET separation. The tabulated trajectory data is contained in Table 5

Nominal trajectory α and β values were combined with the $\Delta\alpha$ and $\Delta\beta$ dispersions to produce the worst case envelopes as follows:

$$\alpha^+ = \alpha + \Delta\alpha^+ \tag{3.1}$$

$$\alpha^- = \alpha - \Delta\alpha^- \tag{3.2}$$

$$\beta^+ = \beta + \Delta\beta^+ \tag{3.3}$$

$$\beta^- = \beta - \Delta\beta^- \tag{3.4}$$

The altitude and velocity profiles for the ascent thermal design trajectory as a function of time for first and second stage flight are presented in Fig. 7. The nominal and dispersed angles of attack and yaw for first and second stage flight are given in Fig. 8.

Section 4
HEATING METHODOLOGY

4.1 General Discussion

The procedure used in calculating the ascent convective heating environments on the ET was first to calculate the undisturbed body alone heating at the flight conditions, then to amplify the undisturbed level with interference factors. The interference factors are a result of shock wave-boundary layer interactions, effects of mated components (SRB's, Orbiter) surface irregularities and protuberance effects. The undisturbed heating was calculated using semi-empirical flat plate methods converted from 2D to axisymmetric body by the Mangler transformations. The interference factors were determined from wind tunnel and flight test data.

4.2 Undisturbed Heating

Ascent convective heating environments were generated using the LANMIN code [3] on the 30° conical nose tip, 10° nose cone and 40° conical section of the LO_2 tank. Heating at the remaining locations i.e., LO_2 tank, Intertank, and LH_2 tank, were generated using the ETCHECK code [4] developed at REMTECH specifically for the ET ascent phase of flight.

A summary of the flowfield, laminar and turbulent heating methods used for each component of the ET is presented in Tables 6 through 9. The rarefied heating methodology, based on the work of Engel and Praharaj [5], is presented in Table 10.

4.2.1 ET Nose Spike

The nose spike is composed of a 30° nose tip and a 10° nose cone afterbody. Shock shape for the spike was determined from the 30° nose tip i.e., a 30° sharp cone while the surface static pressure was determined from the 30° cone for the nose tip and a 10° sharp cone for the 10° after body. Turbulent heating was calculated from Spalding-Chi skin friction correlations and laminar heating from the Eckert Reference Method. A Von Karman Reynolds analogy was used to calculate heating from the skin friction relations. Flight path angles of attack and yaw were accounted for by resolving an effective angle of attack:

$$\alpha_{\text{effective}} = -\alpha \cos\theta_T + \beta \sin\theta_T, \quad \text{deg.}$$

from the Light Weight Tank Design Trajectory dispersed α and β. Heating was therefore calculated as a function of effective angle of attack.

4.2.2 LO_2 Tank, Intertank and LH_2 Tank

As previously stated heating at body points on the LO_2, Intertank and LH_2 Tank were calculated using the ET Check code. The procedure used in calculating the undisturbed heating in this code is to:

a.) Calculate the undisturbed heating (Hu_o) along the trajectory for $\alpha_{\text{eff}} = 0$ deg, then

b.) calculate the undisturbed heating at angles of attack and yaw by:

$$Hu = \left(\frac{Hu}{Hu_o}\right) Hu_o$$

The ratio Hu/Hu_o is undisturbed heating at angle of attack divided by undisturbed heating at zero angle of attack. A study of experimental and analytical data suggested using simple curve fits for the ratio Hu/Hu_o. Curve fits are also used to calculate the recovery enthalpy ratio Hr/H_{r_o}. This approach sacrifices little in accuracy and significantly saves computer time. The curve fits for the heat transfer coefficient and recovery enthalpy ratios are defined as follows:

<u>HEAT TRANSFER COEFFICIENT</u>

<u>Nose Cone $\quad 340.82 \leq X_T \leq 371$</u>

$$\frac{Hu}{Hu_o} = 1.0 \quad (\text{All } M_\infty \text{ and } \alpha_{\text{eff}})$$

<u>Ogive $\quad 371 \leq X_T \leq 760.35$</u>

$$\frac{Hu}{Hu_o} = 1 + F(X_T)\ \alpha_{\text{eff}} \quad (\text{All } M_\infty)$$

where $F(X_T) = -0.07625 + 2.928 \times 10^{-4} X_T - 1.2247 \times 10^{-7} X_T^2$

Barrel $X_T > 760.35$

$$\frac{H}{Hu_o} = 1 + (.02404 + .01246M_\infty)\alpha_{\text{eff}} \quad 0 \leq M_\infty < 4$$

$$\frac{H}{Hu_o} = 1 + .07388\alpha_{\text{eff}} \quad M_\infty \geq 4$$

RECOVERY ENTHALPY

$$\frac{H_r}{H_{r_o}} = \frac{H_\infty + CU_\infty^2(\sin^2\alpha_T + r\cos^2\alpha_T)}{H_\infty + CU_\infty^2(\sin^2\theta_s + r\cos^2\theta_s)}$$

$$C = 0.1998 \times 10^{-4}$$

$$\alpha_T = \theta_s + \alpha_{\text{eff}}$$

$$r = .88(\text{Turbulent})$$

$$r = .85(\text{Laminar})$$

Again the trajectory dispersed angles of attack and yaw were combined into an effective angle of attack for calculation purposes by:

$$\alpha_{\text{effective}} = -\alpha\cos\theta_T + \beta\sin\theta_T, \text{deg.}$$

The methods for defining the heat transfer coefficient and the recovery enthalpy (Hu_o and H_{r_o}) for zero angle of attack will now be discussed.

4.2.2.1 Shock Shape

The nose shape of the ET is bi-conic with a 10° conical spike 13.6″ long attached to a 39.38° nose cone that is 30.2″ long. Flow visualization data from wind tunnel tests have shown that the bow shock shape is determined by the nose spike. The shock angle is determined at each time step from a table stored in the ETCHECK of shock angles as a function of stream Mach Number for a sharp cone with a half angle of 39.38°. The shock wave angle for the 39.38° half angle sharp cone as a function of free stream Mach Number is presented in Figure 9.

4.2.2.2 Surface Pressure

The surface pressure for any location on the ET body is calculated by using a set of empirical equations developed by REMTECH that was based on experimental and analytical pressure data for the ET. The analytical data that were obtained

from MOC solutions for inviscid flow and viscous effects were accounted for by application of viscous interaction theory. A detailed derivation and definition of the empirical relations used to calculate the surface pressure are given in References [5] and [6]. Pressure distributions along the ET surface are shown in Figure 10 at LWT design trajectory conditions where the Mach Number is 3.0 and 4.1. The local surface pressure is a function of the local body angle (θ_s). The equations used to calculate θ_s for the ET body are as follows.

CONE $340.82 \le X_T \le 371$

$$\theta_s = 39.38 \qquad \text{(deg)}$$

OGIVE $371 \le X_T \le 760.35$

$$\theta_s = \tan^{-1} \frac{760.35 - X_T}{r + 446.08} \qquad \text{(deg)}$$

where

$$r = \sqrt{(613.64)^2 - (X_T - 760.35)^2} - 446.08$$

BARREL $760.35 < X_T \le 2058$

$$\theta_s = 0 \qquad \text{(deg)}$$

4.2.2.3 Laminar/Turbulent Heat Transfer

Turbulent and laminar flat plate heating methods are used to calculate the skin friction and heat fluxes for the acreage points. The method of Spalding and Chi is used to calculate the turbulent skin friction which is transformed to turbulent heating through the Von Karman form of the Reynolds analogy. For the laminar case, the method of Eckert is used to calculate the heat transfer parameters. Mangler transformation factors required to transform the flat plate heating to axisymmetric body heating are shown in Figure 11.

The equations used to calculate the running length are given below. The lightning rod spike is ignored and running length is assumed to start at the hypothetical apex of the 39.38° cone.

CONE $340.82 \le X_T \le 371$

$$S = 1.2938(X_T - 336.62) \quad \text{(inches)}$$

OGIVE $371 < X_T \leq 760.35$

$$S = S_{X_T=371} + 613.64 \left[\frac{\cos^{-1} \frac{760.35 - X_T}{613.64} - 50.618^\circ}{57.296} \right] \text{(inches)}$$

BARREL $760.35 < X_T \leq 2058$

$$S = S_{X_T=760.35} + (X_T - 760.35) \quad \text{(inches)}$$

4.2.2.4 Boundary Layer Transition

For undisturbed acreage points, the flight data indicated that transition from turbulent to laminar occurred between the times that $Re_\theta/M_L = 94$ and 47. For disturbed points, it was difficult, if not impossible, to detect when transition occurred. Based on engineering judgements of all the data analyzed, it was decided to force the transition from turbulent to laminar abruptly where $Re_\theta/M_L = 47$ for disturbed flow regions.

4.2.2.5 Rarefied Heating

Rarefied heating to the ET nose spike and 40° nose cone was calculated using correlations from Reference [6]. The methodology is defined in Table 10. The switching criteria from boundary layer heat transfer methods to the rarefied methodology was calculated as follows:

$$A = \frac{M_\infty}{Z_e(Re_\infty)^{0.5}}$$

For	$A \leq 0.05$	boundary layer methods are used
	$0.05 < A < 3.0$	rarefied correlations are used
	$A > 3.0$	free molecular methodology is used.

4.3 Disturbed Acreage Environment Methodology

Approximately two-thirds of the flow over the ET is disrupted due to the presence of the Orbiter mounted on top and the two SRB's mounted on each side of the ET. Early in the Shuttle program, it was decided that the aeroheating methodology would consist of a reference heating for disturbed flow that is amplified due to various flow disturbances such as protuberances, attached bodies, and rough surfaces. This approach was followed for wind tunnel testing, data reduction, environment generation, and flight data reduction/analysis. The calculation approach is summarized below for wind tunnel testing and/or design environment generation.

1. Define undisturbed heating (Hu) over a clean skinned unmated ET at a prescribed flow condition (α, β, V_∞, M_∞, ρ_∞, etc.).
2. Define the proximity amplification factor (Hi/Hu) due to the presence of the Orbiter, SRBs, and adjacent protuberances.
3. Define amplification factors due to surface irregularities; roughness $(H_{\text{rough}}/H_{\text{smooth}})$ and $(H_{\text{stringer}}/H_{\text{smooth}})$.
4. Apply any scaling factors (if applicable) that resulted from analysis of the flight data.

The resultant heating can then be written as

$$H = Hu\left(\frac{Hi}{Hu}\right)\left(\frac{H_{\text{rough}}}{H_{\text{smooth}}}\right)\left(\frac{H_{\text{stringer}}}{H_{\text{smooth}}}\right)\left(\frac{H_{\text{flight}}}{H_{W.T.}}\right)$$

The undisturbed heating for α, $\beta \neq 0°$ was further simplified in this study to

$$Hu = \left(\frac{Hu}{Hu_o}\right) \times Hu_o$$

where Hu/Hu_o is given by simple curve fits previously discussed.

This section will address each amplification factor and give a brief explanation of their derivation and application.

4.3.1 Proximity Amplification Factor (Hi/Hu)

An extensive wind tunnel test program was conducted from 1972-1981 at various facilities throughout the United States to provide a data base for Hi/Hu. Table 11 is an example of Hi/Hu input data required for calculation of a disturbed point. The matrix is for β = -9° to 9° with α = -5°, 0° and 5°. Note that there are two phases (1 and 2) of Hi/Hu definition. Phase I is divided into two parts, one for the first stage launch configuration O/T/S and one for the second state launch configuration (O/T). The flow in Phase I is fully turbulent for acreage points and the values for Hi/Hu are generally provided by the wind tunnel data base. The calculation requires the definitions of Hi/Hu for two Mach Numbers for both the O/T/S and O/T configurations. A linear interpolation of the given Hi/Hu values as a function of M_∞ in the log/log plane provides values of Hi/Hu at intermediate Mach Numbers. This interpolation is required for each α, β combination to fill the main matrix at each intermediate Mach Number (time point). Figure 12 demonstrates how Hi/Hu is interpolated/extrapolated between and beyond the given Mach Numbers for phase 1. In the calculation scheme the time that the SRBs separate is an input which triggers the transfer from the O/T/S data base to the O/T data base.

Phase 2 is defined as that period of second stage flight when the flow is assumed to be laminar and rarefied. A change in the Hi/Hu format occurs between phase 1 and phase 2. For phase 1, Hi/Hu is assumed to be a function of α, β and M_∞ whereas for phase 2, Hi/Hu is assumed to be only a function of Mach Number. There was an insufficient data base for simulated second stage flight conditions to define the effects of α and β on Hi/Hu so the approach was to envelope the existing data at each Mach Number. This conservative assumption is not considered very significant since the aeroheating environment during the phase 2 period of flight is low.

The switch from the phase 1 to the phase 2 Hi/Hu data base is defined as the first time that the boundary layer is laminar in the undisturbed environment solution. A smooth transition can be accomplished if the user applies the following equation at the phase 1/phase 2 interface when preparing the phase 2 Hi/Hu data base.

$$\left(\frac{Hi}{Hu}\right)_{\text{laminar}} = \left(\frac{Hi}{Hu}\right)_{\text{turbulent}}^{1.47}$$

4.3.2 Surface Roughness $\left(\frac{H_{\text{rough}}}{H_{\text{smooth}}}\right)$

The foam which is sprayed on the ET leaves a rough textured and sometimes wavy surface which, for turbulent boundary layers, can significantly increase aerodynamic heating. Wind tunnel tests were conducted to quantify the amplification of heating due to the roughness/waviness of the foam surface. The data was incorporated into existing empirical methods and surface roughness factors were derived for design flight conditions. The details of the roughness/waviness tests and analysis are reported in References [7] - [9]. The surface roughness/waviness factors (R.F.) that are currently used in design environment calculations are as follows:

Nose cone (39.38°)	R.F. = 1.0 (SLA finish fairly smooth)
Ogive	R.F. = 1.3
Ogive Barrel	R.F. = 1.1
Intertank	R.F. = 1.15
LH2	R.F. = 1.1

The roughness/waviness (R.F.) factor is applied only for acreage points when the boundary layer is turbulent.

4.3.3 Intertank Stringer/Waviness Factor $\left(\frac{H_{\text{stringer}}}{H_{\text{smooth}}}\right)$

The intertank ($852.8 \leq X_T \leq 1123.15$) cylindrical structure consists of eight joined panels (two ribbed panels on each side and six panels with external stringers). Figure 13 presents the intertank TPS design for the series of lightweight tanks (LWT) 1-44. With the advent of the two gun spray equipment series of tanks > LWT 44, the E.T. will return to an all CPR-488 TPS on the intertank and no non-stringered external surface areas. Based on a study conducted by Engel [10] that analyzed wind tunnel heat transfer data reported by Brandon [11] for wavy walls, the following empirical relationships are recommended for minor and major crossflow regions. These regions are defined in Figure 14.

Minor crossflow regions are defined as those where the flow disturbances due to the presence of the Orbiter and SRBs are small and the crossflow angle ϕ is less than $\approx 9°$. The equations recommended to calculate stringer factor effects on average heating for minor crossflow regions are given below.

$$
\begin{aligned}
\phi &= |\alpha \sin\theta_T - \beta \cos\theta_T| \quad \text{crossflow angle in deg.}\\
A &= 1.2 + .01867\,\phi\\
B &= \log A \log M_\infty / .72428\\
W.F. &= 10^B
\end{aligned}
$$

where W.F. is the average heating amplification over a wavelength. Peak heating areas near the cap of the stringers are not accounted for in the above correlation.

There are three major crossflow regions on the intertank. Each side of the intertank has significant crossflow due to the presence of the SRBs and the top of the tank experiences significant crossflow due to the presence of the orbiter. In these highly disturbed regions, the crossflow angle can experience values from moderate ($<9°$) to $\approx 90°$ depending on the attitudes (α, β) of the vehicle. Due to this reason, it was decided to envelope the factors between $0 \leq \phi \leq 90°$ which results in the stringer/waviness factor for the major crossflow regions to only depend on M_∞. The following table for the stringer/waviness factor is recommended for the major crossflow regions when the boundary layer is turbulent.

M_∞	Stringer/Waviness Factor
1	1.0
3	1.28
4	1.37
5.3	1.46

These values again only represent the average amplification of heating over a wavelength. Later in the flight when the boundary layer becomes laminar and rarefied, the stringer factor is assumed to be 1.0.

4.3.4 Flight/Wind Tunnel Scale Factors $\left(\frac{H_{\text{flight}}}{H_{\text{W.T.}}}\right)$

The Hi/Hu proximity factors discussed in Section 4.3.1 are normally based on wind tunnel data measured on small models of the full scale ET. There were six instrumented flight ETs that were flown between April 12, 1981 and June 18, 1983 that measured aerodynamic heating and pressures at various surface locations. The analysis of the flight data showed for certain locations and flight regions that the wind tunnel and flight data did not agree. Flight test data from STS 1-3, 5, 6 and 7 consequently were used to generate scale factors between wind tunnel and flight. The scale factor:

$$f = \frac{Hi/Hu)_{\text{flight}}}{(Hi/Hu)_{\text{wind tunnel}}}$$

was applied as a direct multiplier on the wind tunnel data at M=3.00 and 4.00,

$$Hi = (Hi/Hu)_{\text{wind tunnel}} \times f \times Hu_o$$

to adjust the wind tunnel data level to that commensurate with flight measurements.

A listing of the wind tunnel and flight test Hi/Hu data base as well as the tunnel to flight scaling factors for each body point is on file at REMTECH, Inc.

Section 5
ASCENT ENVIRONMENTS

5.1 Timewise Environments

Timewise ascent thermal design environments were generated at 367 acreage body point locations on the External Tank. These environments are composed of aerodynamic convective and plume convective heating. Environments are computed for lift off, first stage ascent, SRB staging and second stage ascent through ET separation. SRM and SSME radiation heating are not accounted for. Environments at body point locations for $X_T < 1871$ are composed of aerodynamic convective heating only. For body points aft of $X_T \geq 1871$, plume convection has been included.

Due to the complex flow field interaction around the E.T. base region, several ground rules were established to define the application of plume and aeroheating. For the acreage locations, these are:

1. ET Aft Dome
   (a) No aeroheating
   (b) Plume convective heating throughout first stage
2. ET Aft Barrel Acreage ($X_T = 2000$ to $X_T = 2058$)
   (a) Aeroheating from 0 to 95 seconds and throughout second stage
   (b) Plume convective heating from 95 seconds to end of first stage
3. ET Aft Barrel Acreage ($X_T = 1871$ to $X_T = 2000$)
   (a) Aeroheating from 0 to 95 seconds and throughout second stage
   (b) More severe of either aeroheating or plume convective heating from 95 seconds to end of first stage

For those body points where plume heating was the main contributor between 95 and 126 seconds, design plume heating rates were generated versus time and integrated along with the convective aeroheating component to give the total load.

An example of the timewise environments is presented in Table 12. This particular environment is for Body Point 7432 located at $X_T = 1132.2$ in. and $\theta_T = 315°$. Parameters listed include trajectory time, altitude (ALT), vehicle velocity (vel) and Mach number, angle of attack (ALP), angle of sideslip (BET), effective angle of attack (AEFF), recovery enthalpy (HR), heat transfer coefficient (HCNV), cold wall heating rate (QDOT), integrated heat load (Q_{LOAD}) and the Hi/Hu interference heating factor (INTRF). Tabulated timewise environments similar to those presented in Table 12 are on file at REMTECH, Inc. for each of the 367 body point locations.

5.2 Environment Presentation

Summary environments in the form of tabulated maximum cold wall heating rates (Tw=460°R) and integrated heat load for each body point are presented in Table 13. The maximum heating rates listed pertain to convective aeroheating only. The loads include plume convection for body point locations $X_T > 1872$. The Rockwell IVBC-3 environments are included for comparison purposes.

Most of the body points on the aft barrel section and aft dome are driven by plume convection between 95 and 126 seconds. These points along with the maximum aeroheating and plume convection heating rates are listed in Table 14. The dominant heating component between 95 and 126 seconds is also identified. As before, the Rockwell IVBC-3 maximum aeroheating rate is listed for comparison.

Timewise environments for each body point are presented in Volume II in the form of cold wall heating rate versus time. Comparisons are made with the RI IVBC-3 counterpart. Integrated heat loads are tabulated at the top of each plot. These environments contain both aeroheating and plume convection. Comparative comments are made giving the relative status of each environment from the stand point of TPS impact. The environments are presented in numerical order according to body point and are grouped according to component i.e., LO_2 Tank, Intertank, LH_2 Tank, etc. Green spacer pages separate each group of body points. In addition, the summary environments presented in Table 13 are also presented in Volume II.

Section 6
REMTECH/ROCKWELL IVBC-3 ENVIRONMENT COMPARISON

Of the 380 acreage body point locations on the E.T. for which environments were calculated and comparisons made, 30 were not acceptable and required an in-depth analysis. These are listed in Table 15. The remainder of body point locations exhibited a favorable comparison between the REMTECH design environment and the Rockwell IVBC-3 counterpart. The guidelines used to judge whether an environment was comparable or unacceptable are:

1. Does the heating rate history track the IVBC-3 rate in the time frame 80 to 120 seconds when maximum heating occurs,
2. Does the maximum heating rate and integrated heat load compare between the two, and if not, are the REMTECH values lower than the IVBC-3 values, (heat load was considered secondary in importance) and lastly,
3. If the REMTECH environment is greater than the RI IVBC-3 environment, does it impact the TPS.

6.1 40° Cone

The Rockwell environments for Body Points 70500, 70550, 70575, 70600, 70650, and 70675 are considerably lower than the REMTECH calculations. A summary plot comparing the axial maximum cold wall heating rate distribution between the two methods is presented in Figure 15. The wind tunnel data for this region was laminar/ transitional where as the flight data was transitional/turbulent. The REMTECH environments included the nose spike interference effects that were based on flight data. In addition, the REMTECH environments assumed that the amplification factor over the entire 40°. cone surface was constant. The Rockwell environments were based on wind tunnel distributions that measured low heating levels for XT < 350. The difference between Rockwell and REMTECH, however, should not impact the current TPS design since the area is designed by the environment at B. P. 70700 (XT = 354).

6.2 LO_2 Tank

The REMTECH design heating rates for Body Points 71363, 71369, 71381, 71388, and 71394 on the LO_2 Tank do not track the Rockwell counterpart in the time frame 80 to 110 seconds. The REMTECH maximum rate is higher by generally 1 Btu/fts-sec. In investigating this anomaly, it was found that the REMTECH calculations were generally higher on the LO_2 Tank from $X_T = 350$ to approximately $X_T = 600$ at other body point locations also. This is shown in Figure 16 which is a comparison of the Rockwell and REMTECH maximum heating rates on the foreward porton of the LO_2 Tank. The reason for this discrepancy could not be found. However, the TPS design is not impacted since the difference in heating amounts to a difference in TPS of approximately 0.1 inches of CPR. This is well within the uncertainty of 0.38 inches of TPS allowed during application. TPS application tolerances are defined in Table 16.

6.3 Intertank

Table 15 lists the Intertank body points where discrepancies between Rockwell and REMTECH existed i.e., the REMTECH environments were higher. At all of these points the agreement is acceptable and the difference in heating in the 80 - 130 second time frame results in approximately a difference of 0.1 inches of CRR being removed due to ablation. This is within the tolerance allowed in applying the TPS (see Table 16). However, at Body Point 7355, which is located at $X_T = 961$ and $\theta_T = 270$ deg in the SRB foreword attach area (see Fig. 4c), the difference in heating is significant enough to impact the TPS in that area. The current design in that area is a nonstringered configuration as shown in Fig. 17a (Ref. 12). For this case which covers LWT 16-43, the configuration covers the Rockwell design environment with a peak heating rate of 16.5 BTU/ft^2sec. The Rockwell environment is calculated for a non stringered configuration and REMTECH agrees with this calculation as shown in Fig. 18. However, with the advent of the two gun spay equipment series of tanks (LWT $\geq$ 44), the E.T. will return to all CPR-488 TPS on the intertank. With this configuration, Fig. 17b, there will be no non stringered external surface areas. In this light, when the stringer factors are added to the heating calculation, REMTECH predicts a peak rate of 21.8 BTU/ft^2sec and the heating is considerably higher (Fig. 18) than for the non-stringered configuration. The difference in heating results in a difference of approximately 1.00 inch of CPR-488 removal. Consequently, the design environment at B.P. 7355 needs to be recalculated by Rockwell with the consideration of using stringer factors after LWT 43.

6.4 LH_2 Tank

A lack of agreement between RI IVBC-3 and REMTECH was found at Body Point locations 1401, 6582, 7694, 7931, and 7935 on the LH_2 Tank.

Examining the environments in the vicinity of B.P. 1401, Figure 19, shows that the IVBC-3 environment is high from a consistency standpoint within the Rockwell set. In addition, the H_i/H_u data base was checked and the interference factors listed for the IVBC-3 design environment are not consistent with the wind tunnel data base (T/C 5252 FROM IH-97).

The Rockwell design environment for B.P. 6582 is believed to be high. This body point is located underneath the LO_2 Feedline at X_T = 1127. Maximum design heating rates at similar locations on the LH_2 Tank are in the 1.0 to 3.0 Btu/fts-sec, whereas the environment for 6582 is 5.8. (See B.P.s 6590-6593, and 6603-6606). Examining the interference factor data base, the factors for B.P. 6582 range from 10 to 13 in the Mach 3.0 to 4.0 time frame. They should be in the 2 to 4 range.

Maximum heating rates in the vicinity of B.P. 7694 are presented in Figure 20. The plot indicates that the REMTECH environment is too high. However, when the H_i/H_u wind tunnel data base is examined, Figure 21, the Rockwell interference factors appear low. The physical reason for the H_i/H_u data at this location being high is not known, (T/C = 853 IH-72) however, the heating level is low enough that there is no TPS impact.

Rockwell environments for Body Points 7391 and 7395 are low with possible TPS impact. A circumferential plot of maximum cold wall heating rate at approximately X_T = 2058 is presented in Figure 22. This plot shows the distribution of environments in the vicinity of B.P.s 7931 and 7935. Body Point 7931 is located immediately in front of the LH_2 Feed Line. Heating would be expected to be high due to the separation immediately upstream of a protuberance. The H_i/H_u data base for this location was examined along with the interference factors tabulated in the design environment. This is shown in Figure 23 for the Mach 3.0 and 4.00 results. Corresponding angles of attack and sideslip were obtained from the LWT Trajectory and the interference factors from the REMTECH and Rockwell environments plotted at these locations. The results show that the IVBC-3 data are low. A similar investigation was carried out for B.P. 7935. The H_i/H_u versus Beta data base (T/C 5051 IH-97) is shown in Figure 24 along with the Rockwell and REMTECH interference factors listed in the respective design environments. The results show the Rockwell interference factor to be low at Mach 3.00, but in agreement with the REMTECH factor at Mach 4.00.

Section 7
CONCLUSIONS

Ascent thermal design environments were generated at 367 acreage body point locations on the External Tank. These represented an independent set of calculations and served as a check on the Rockwell IVBC-3 set of design environments used to design the ascent phase of flight. Direct one on one comparisons were made between Rockwell and REMTECH. Of the 367 location investigated, 30 were questionable requiring in depth analysis. Of these 30 only three represented a possible TPS impact. These are B.P.s 7355 on the intertank and 7931, 7935 on the LH_2 Tank. At these locations, the Rockwell environments are considered low and need to be revisited.

References

[1] Space Shuttle IVBC-3 Aerodynamic Heating Design Environments for the External Tank Data Tape DN 2217, February 1988.

[2] Crain, William K., and Nutt, Kenneth W., "NASA/Rockwell International IH-97 Space Shuttle Heating Test," AEDC-TSR-82-V37, December 1982.

[3] Engel, Carl D., and Praharaj, Sarat C., "MINIVER Upgrade for the AVID System Volume 1 - LANMIN Users Manual," NASA CR 172212, August 1983.

[4] Warmbrod, J.D., and Bancroft, S.A., "ETCHECK - Ascent Aerodynamic Heating Computer Program for External Tank," REMTECH inc. RTR 032-02, 1985.

[5] Engel, C.D. and Praharaj, S.C., "External Tank Rarefied Aerothermodynamics," REMTECH inc. RTR 022-1, January 1978.

[6] Engel, C.D. and Praharaj, S.C., "ET Aerothermodynamics Study," REMTECH inc RPR 022-16, September 1977.

[7] Engel, C.D. and Praharaj, S.C., "ET TPS Development Criterion and Flight Instrumentation Program," REMTECH inc RPR 032-02, May 1978.

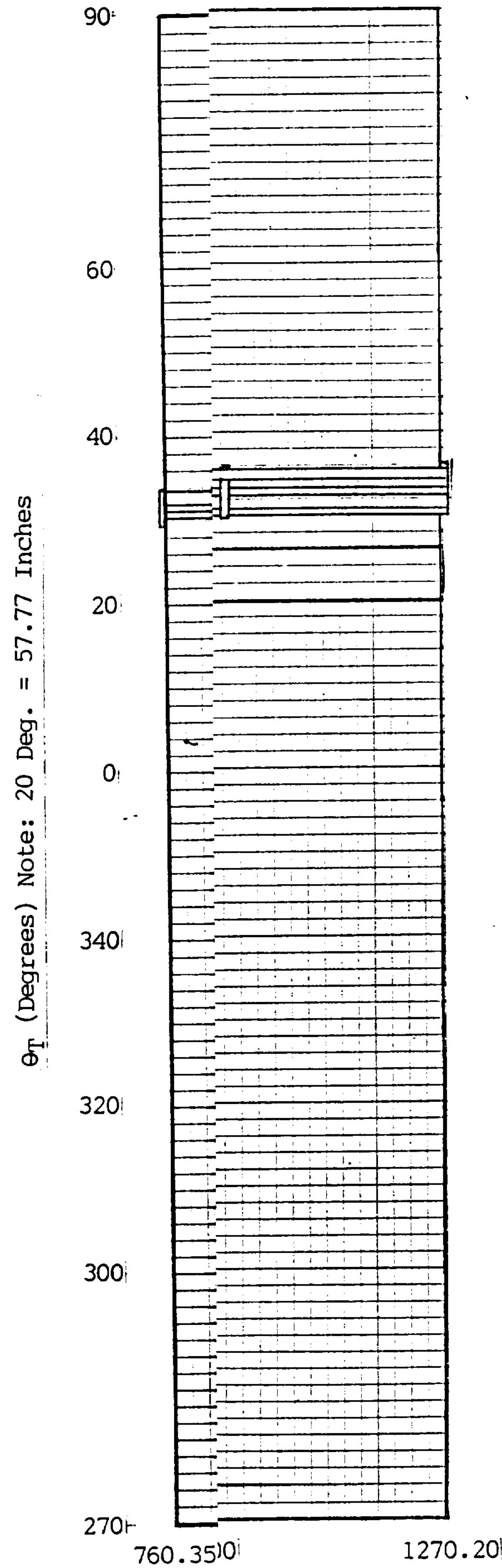
[8] Engel, C.D., "External Tank Surface Roughness Heating," REMTECH inc RTR 017-3, November 1977.

[9] Praharaj, S.C., Engel, C.D., and Warmbrod, J.D., "Aeroheating Design Methodology for the Space Shuttle External Tank," REMTECH inc RTR 032-01, July 1981.

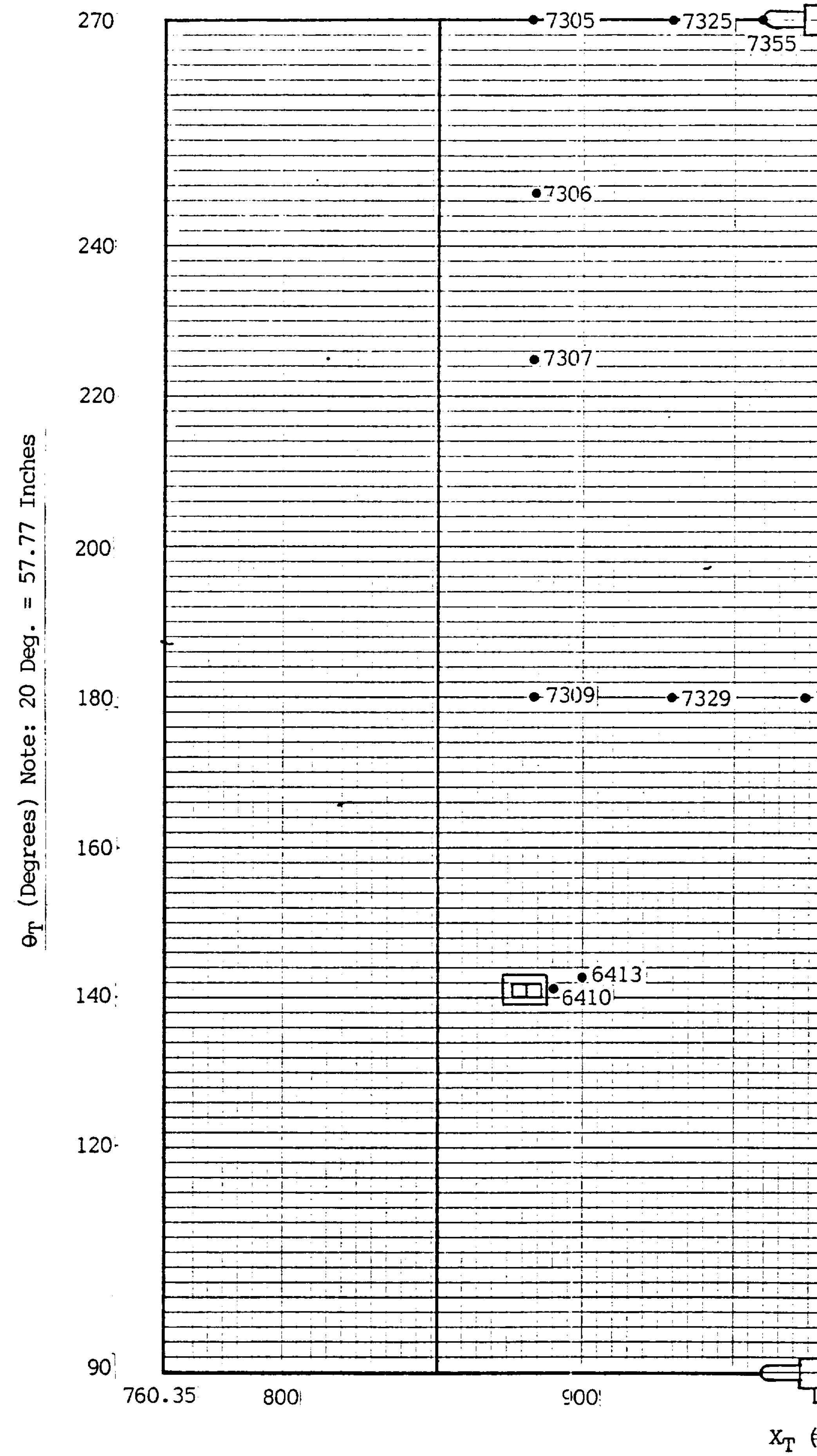
[10] Engel, C.D., "ET Intertank Stringer Interference Factor Methodology," REMTECH inc. RTN 032-1, January 1979.

[11] Brandon, H. J. and Masek, R.V., "Measurement and Correlation of Aerodynamic Heating to Surface Corrugation Stiffened Structures in Thick Turbulent Boundary Layers," NASA CR-132503, September 1974.

[12] "Space Shuttle External Tank LWT Thermal Data Book," MMC 80900200102, Revision C, March 1988.

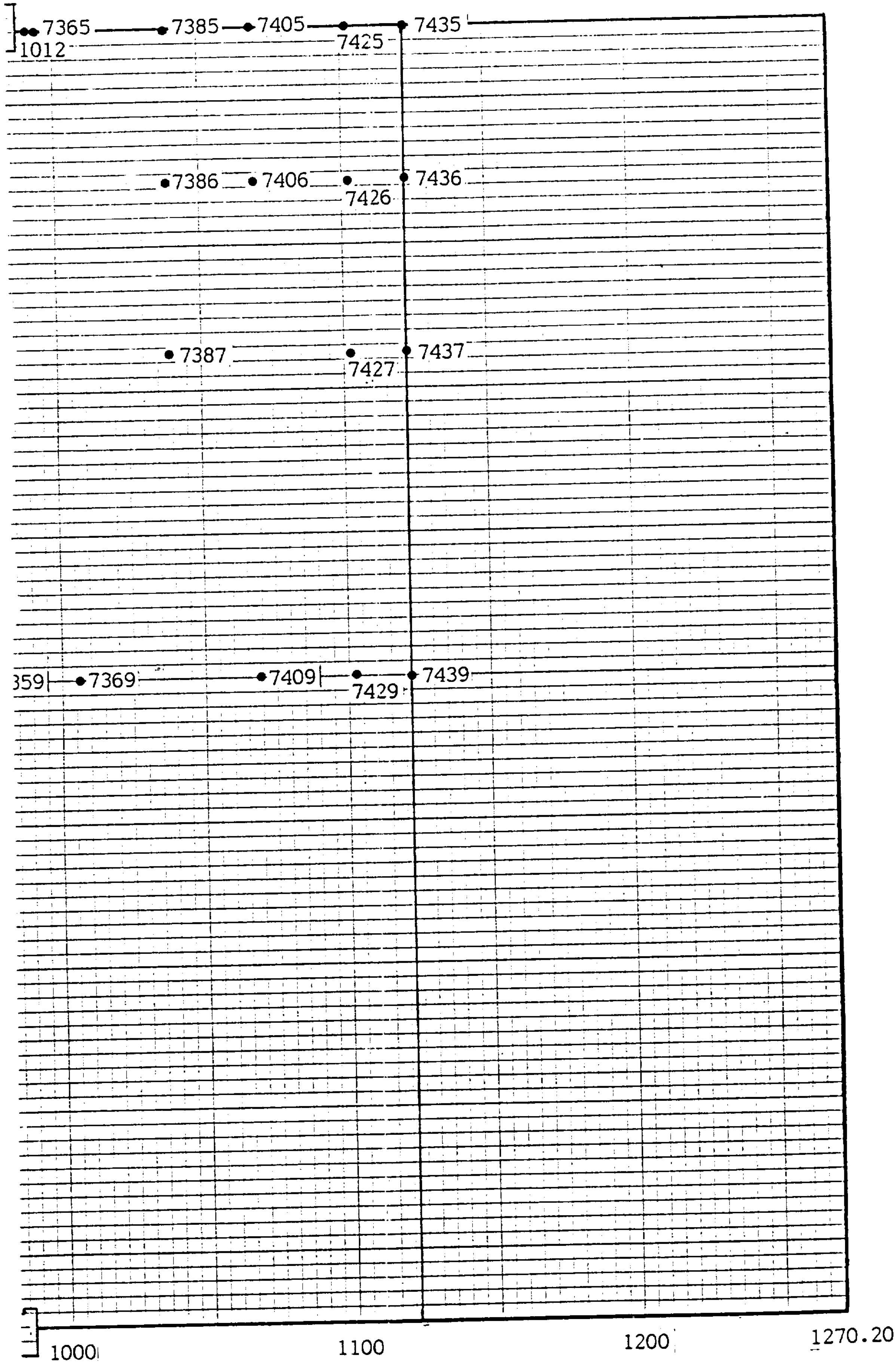

90
60
40
20
0
340
320
300
270
θ_T (Degrees) Note: 20 Deg. = 57.77 Inches
760.350
1270.20

REMTECH



b) $\theta_T = 90$

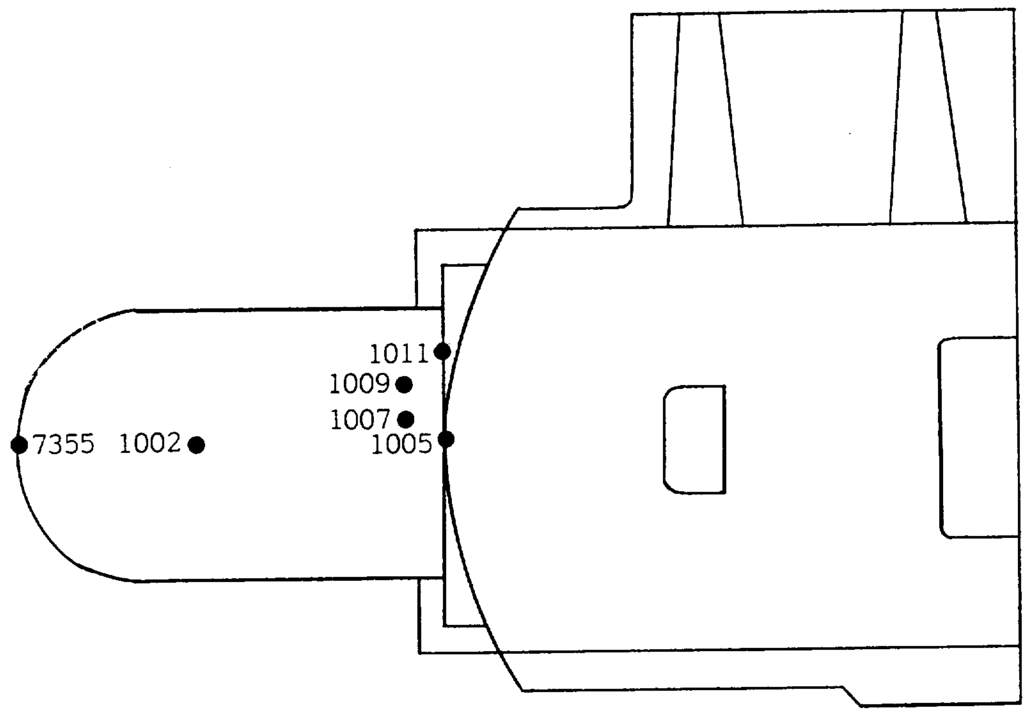
Figure



nches)

- 180 - 270 deg.

Continued

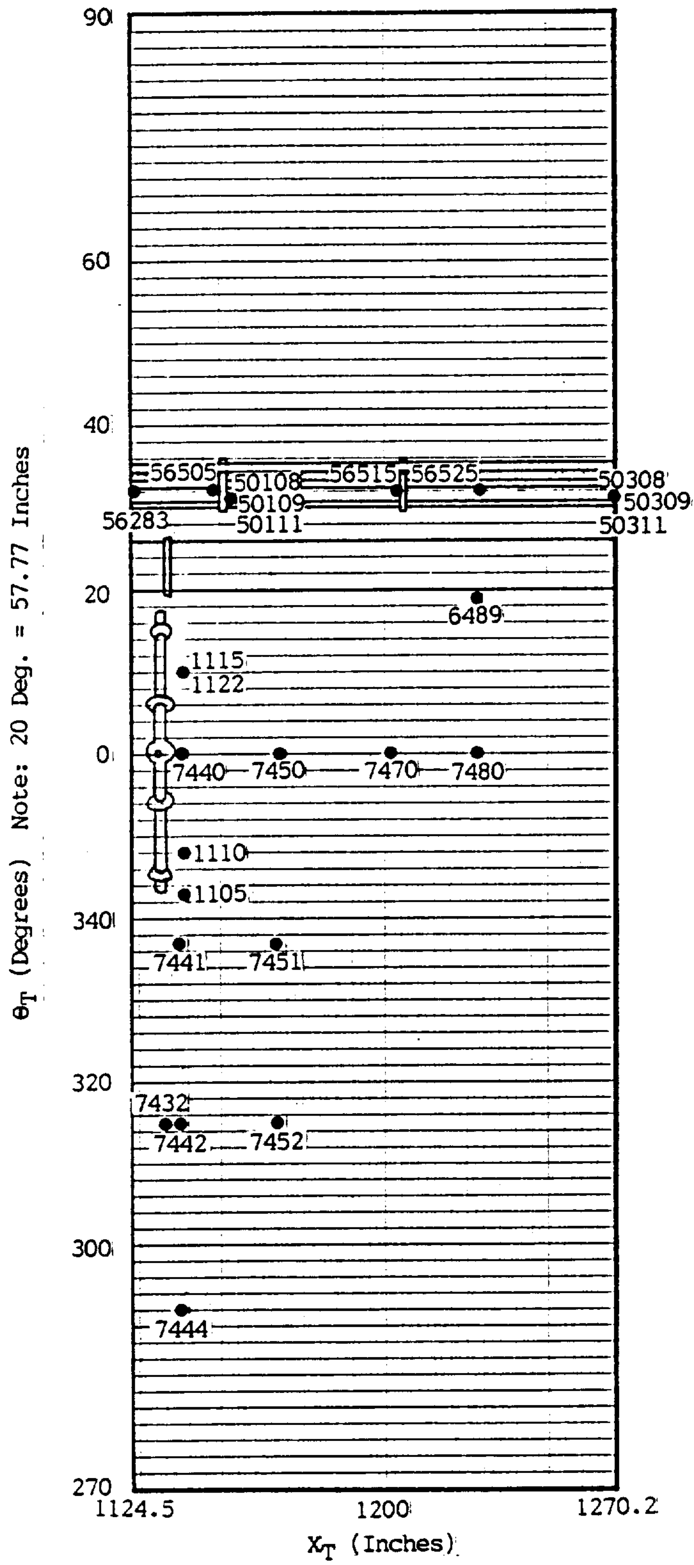


Body Point Number	X_T	θ_T
7355	961.22	270.0
1002	965.22	270.0
1007	970.22	270.5
1009	970.22	271.0
1005	971.22	270.0
1011	971.22	271.6

Note: These points are not on the Bolt Catcher but on the Intertank acreage beneath it.

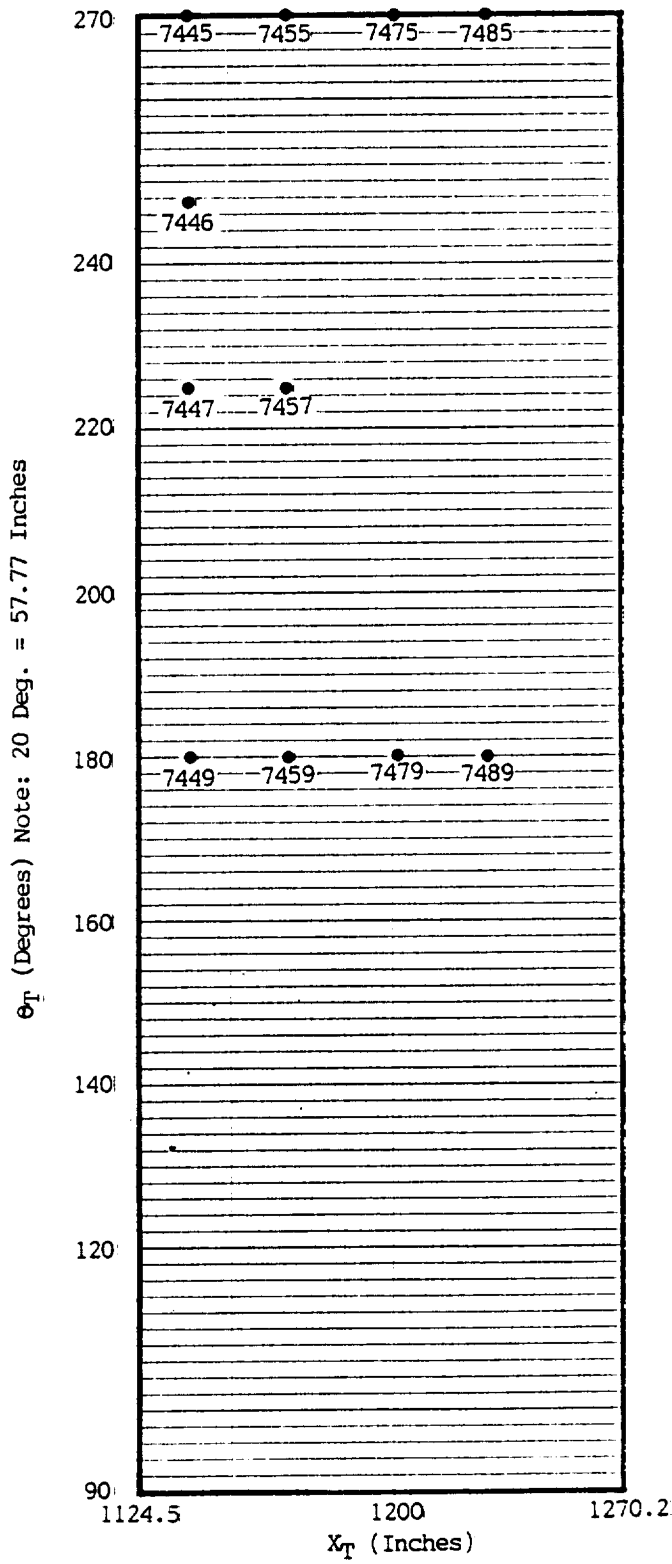
c) Acreage Beneath Boltcatcher

Figure 4: Concluded



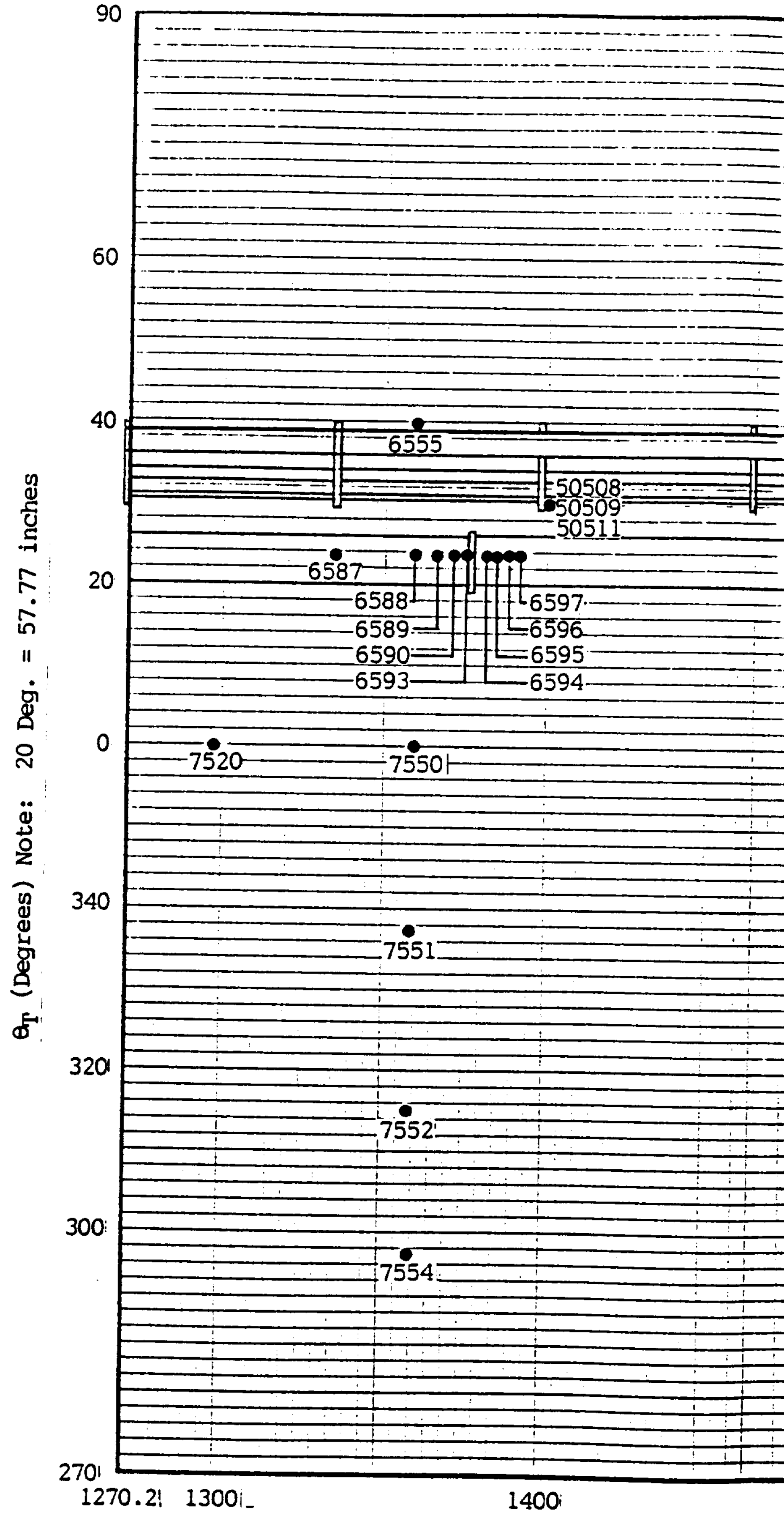
a) LH_2 Tank Forward Section Acreage ($\theta_T = 270$ - 0 - 90)

Figure 5: LH_2 Tank Acreage Body Point Locations

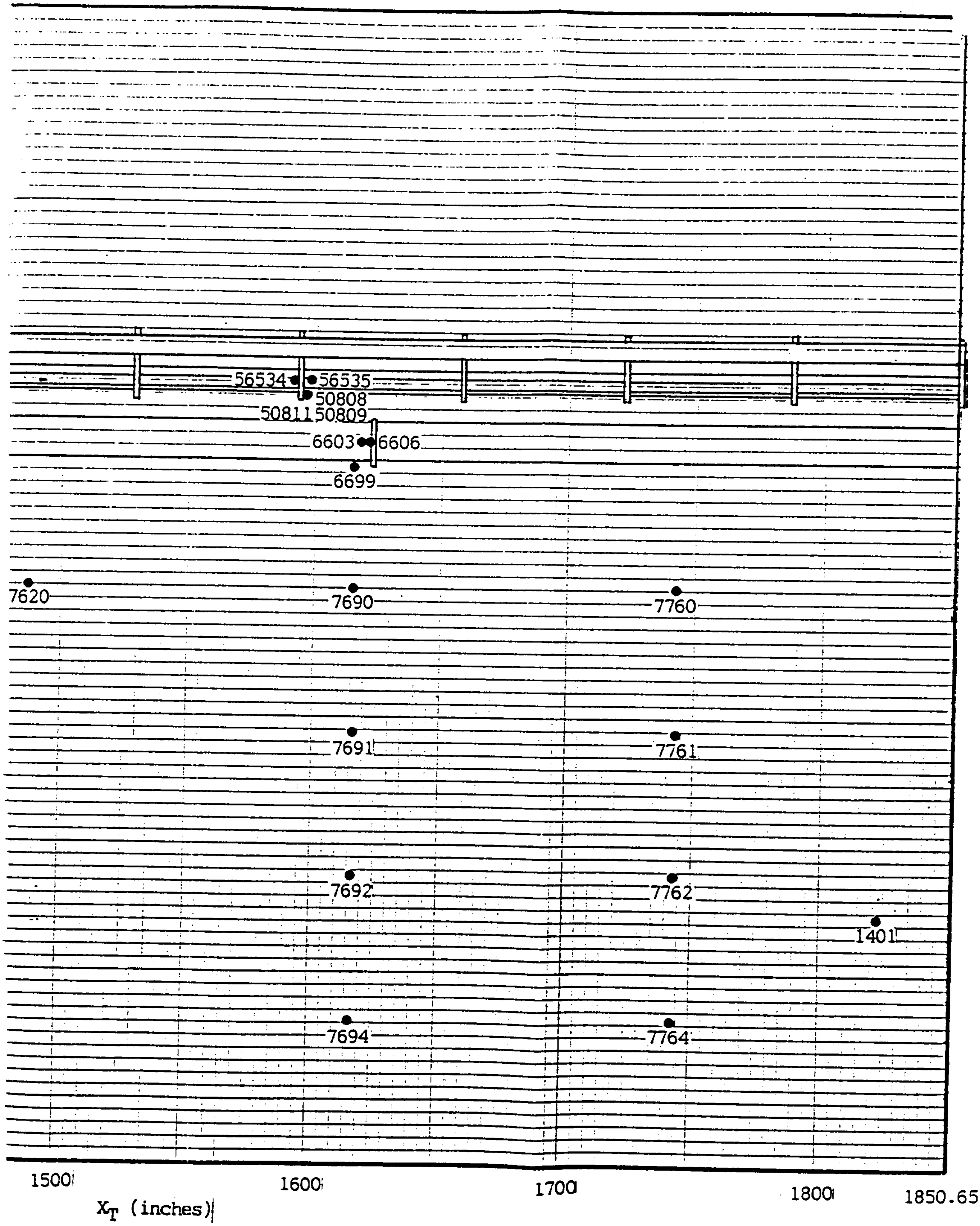


b) LH_2 Tank Forward Section Acreage (θ_T = 270-180-90)

Figure 5: Continued


90
60
40
20
0
340
320
300
270
1270.2
1300
1400
θ_T (Degrees) Note: 20 Deg. = 57.77 inches
6555
50508
50509
50511
6587
6588
6589
6590
6593
6597
6596
6595
6594
7520
7550
7551
7552
7554

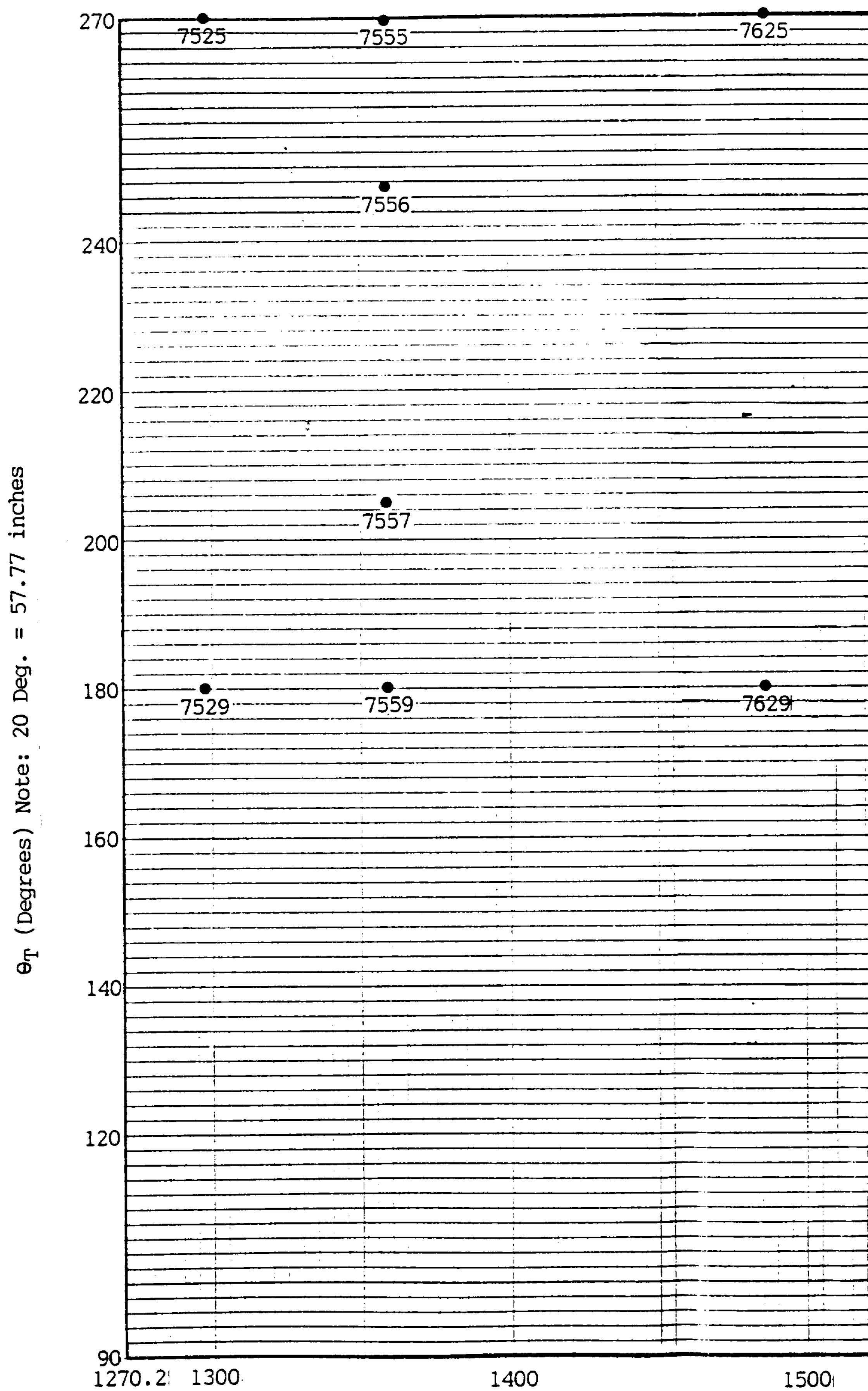
c) LH_2 T



.nk Mid Section Acreage ($\theta_T = 90$ - 0 - 270)

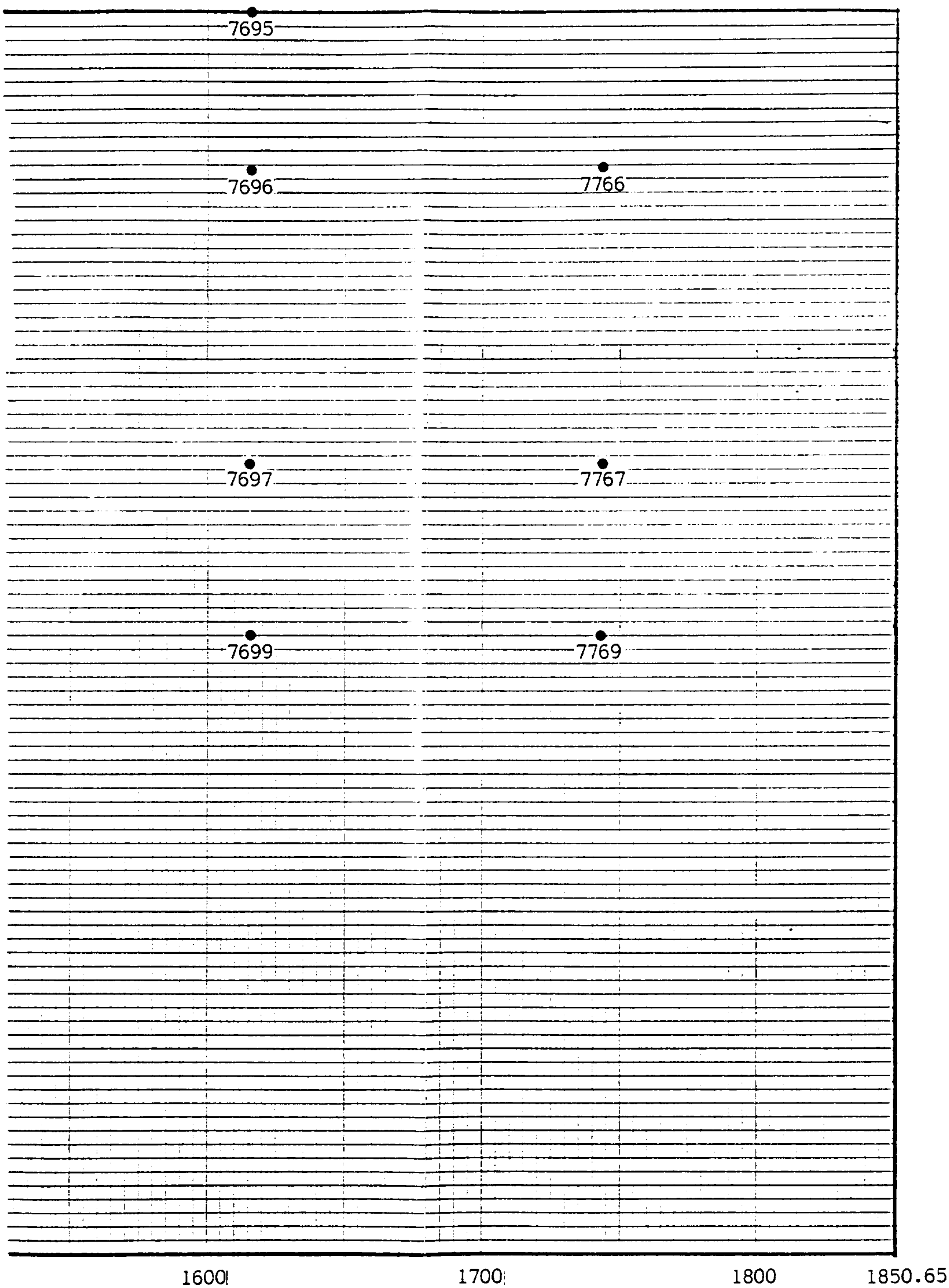
Figure 5: Continued

REMTECH



d) LH_2 Tank Mid Section Acre

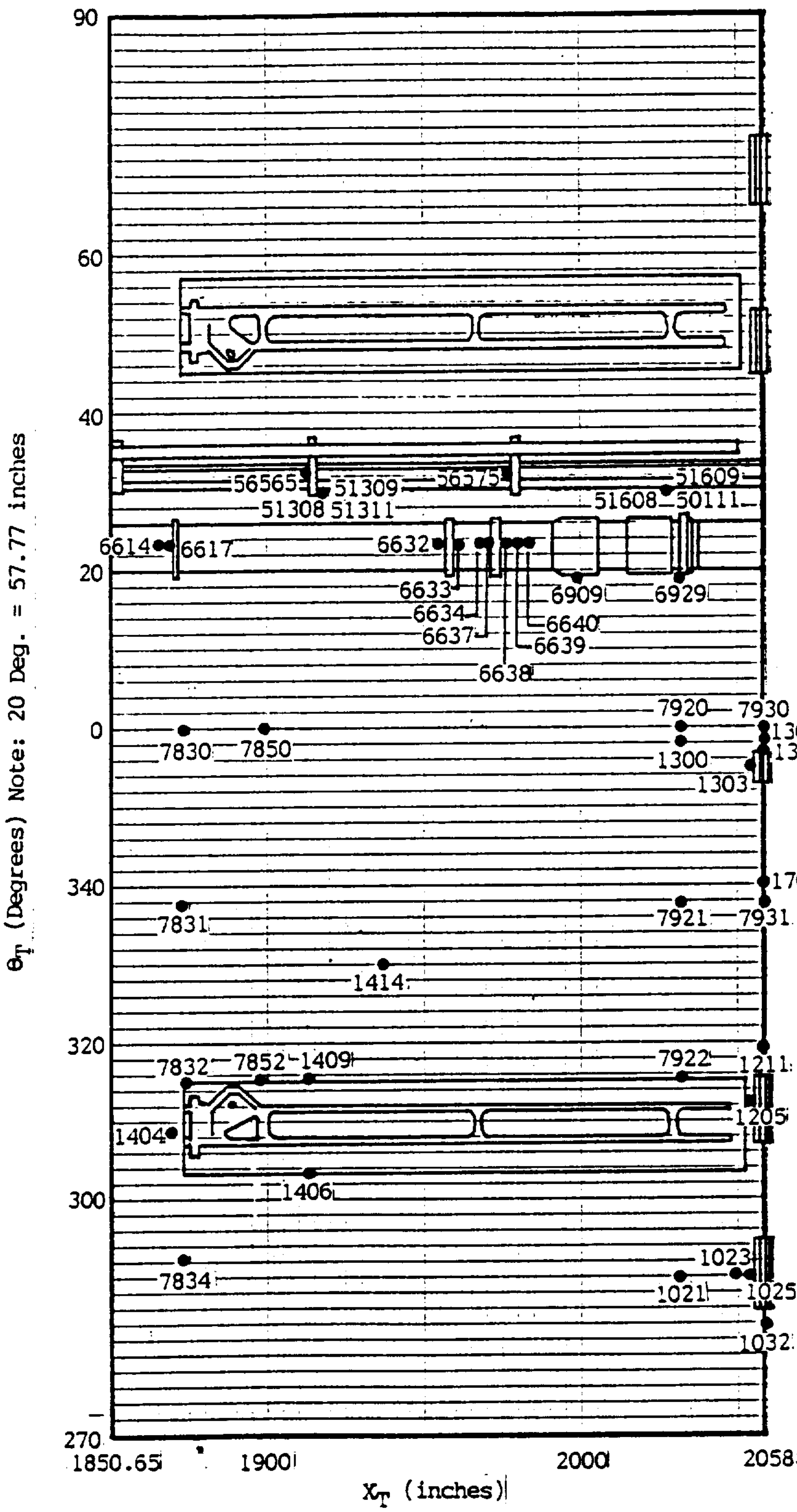
Figure 5



X_T (inches)

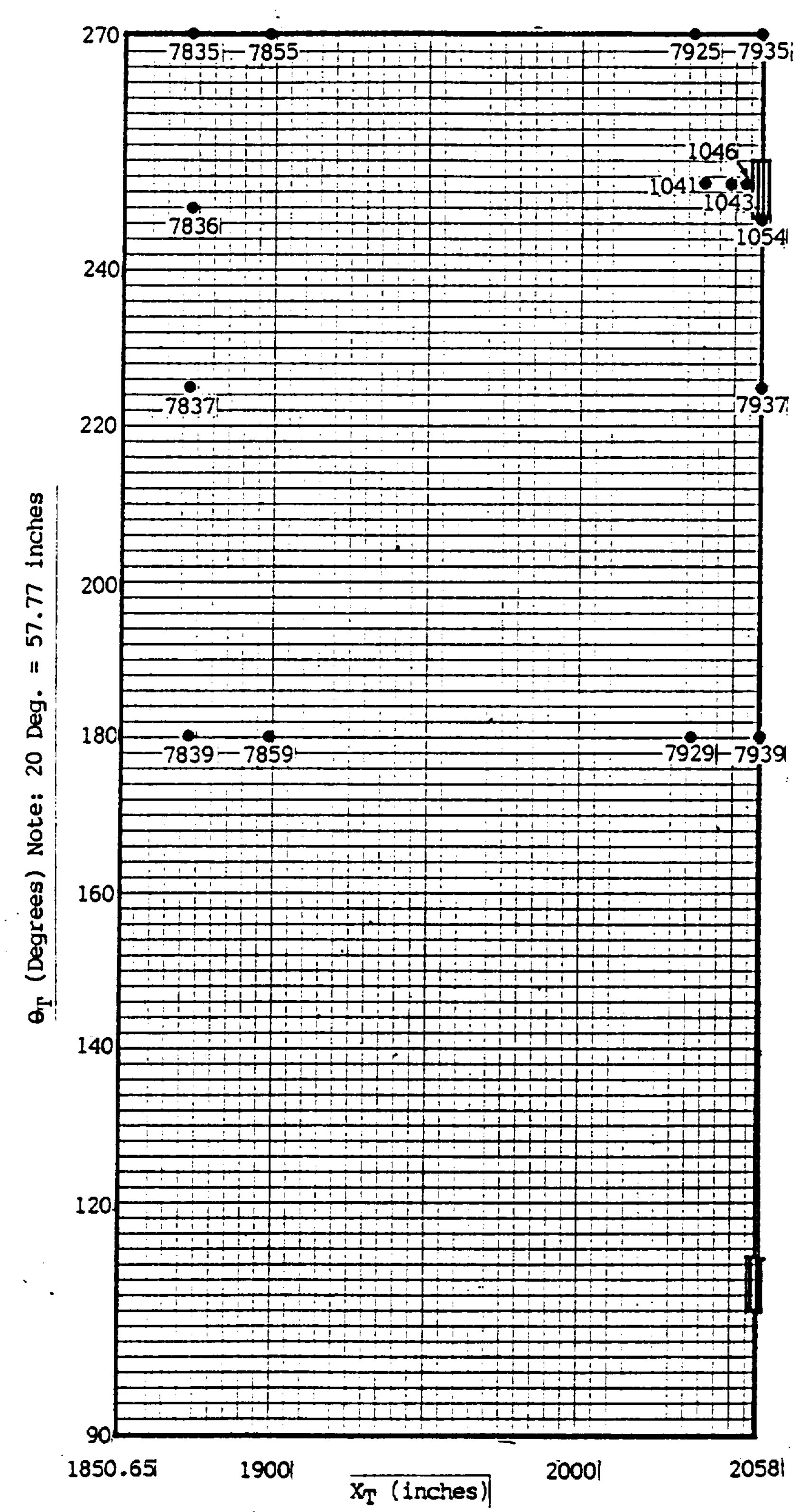
e (θ_T = 270 -180-90)

Continued



e) LH_2 Tank Aft Section Acreage (θ_T 90 - 0 - 270)

Figure 5: Concluded



f) LH_2 Tank Aft Section Acreage (θ_T = 270 -180-90)

Figure 5: Continued

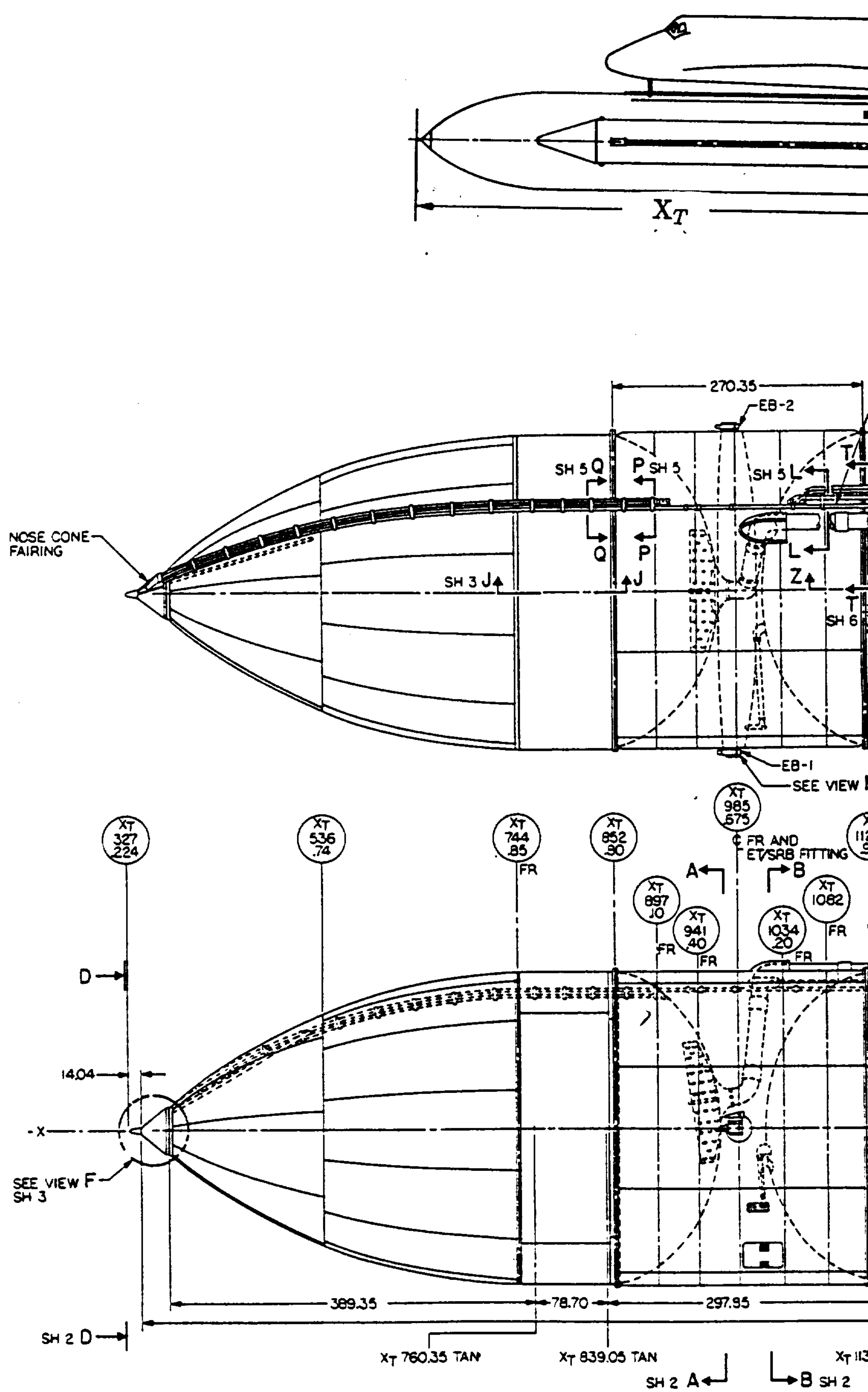
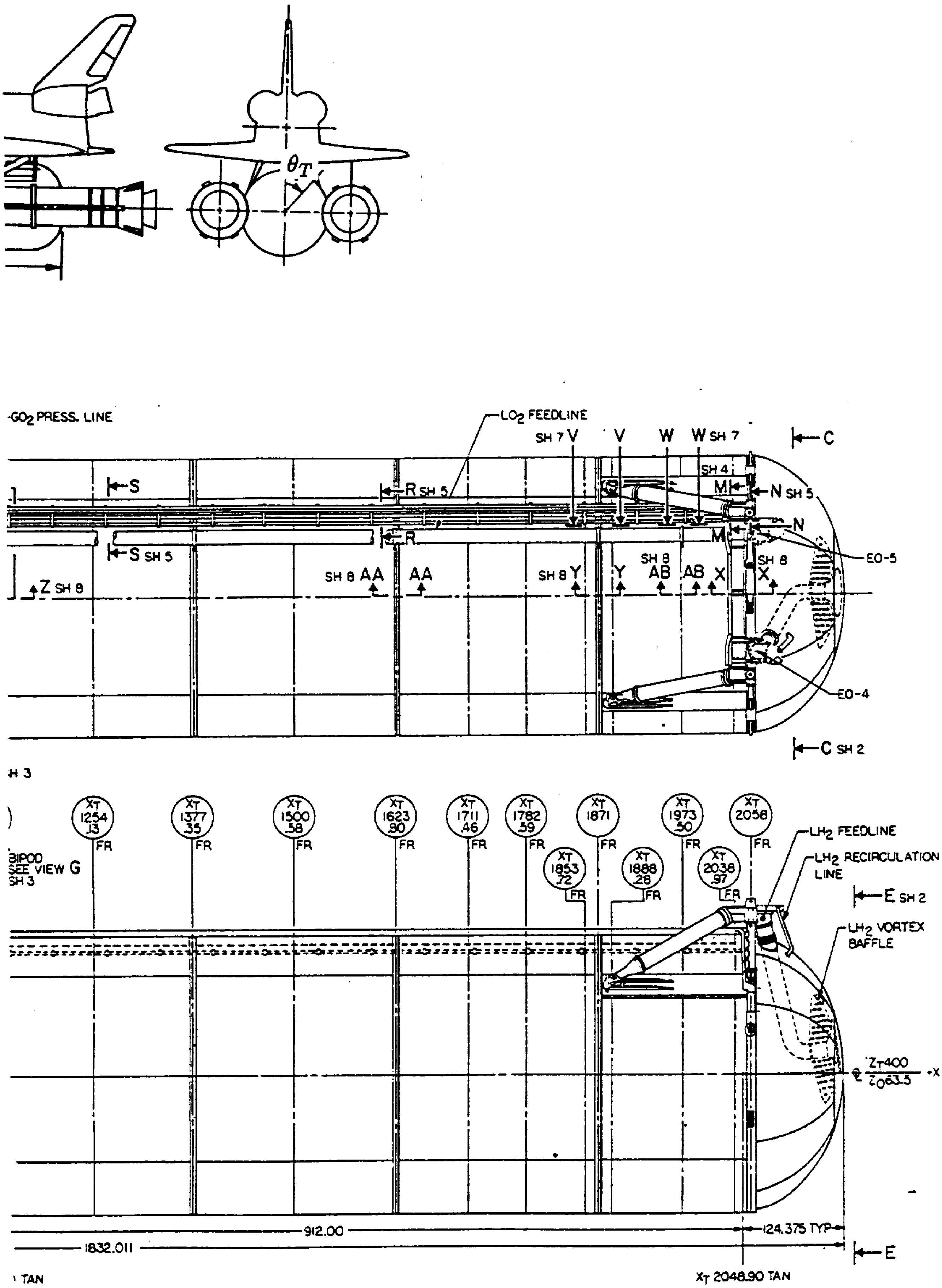
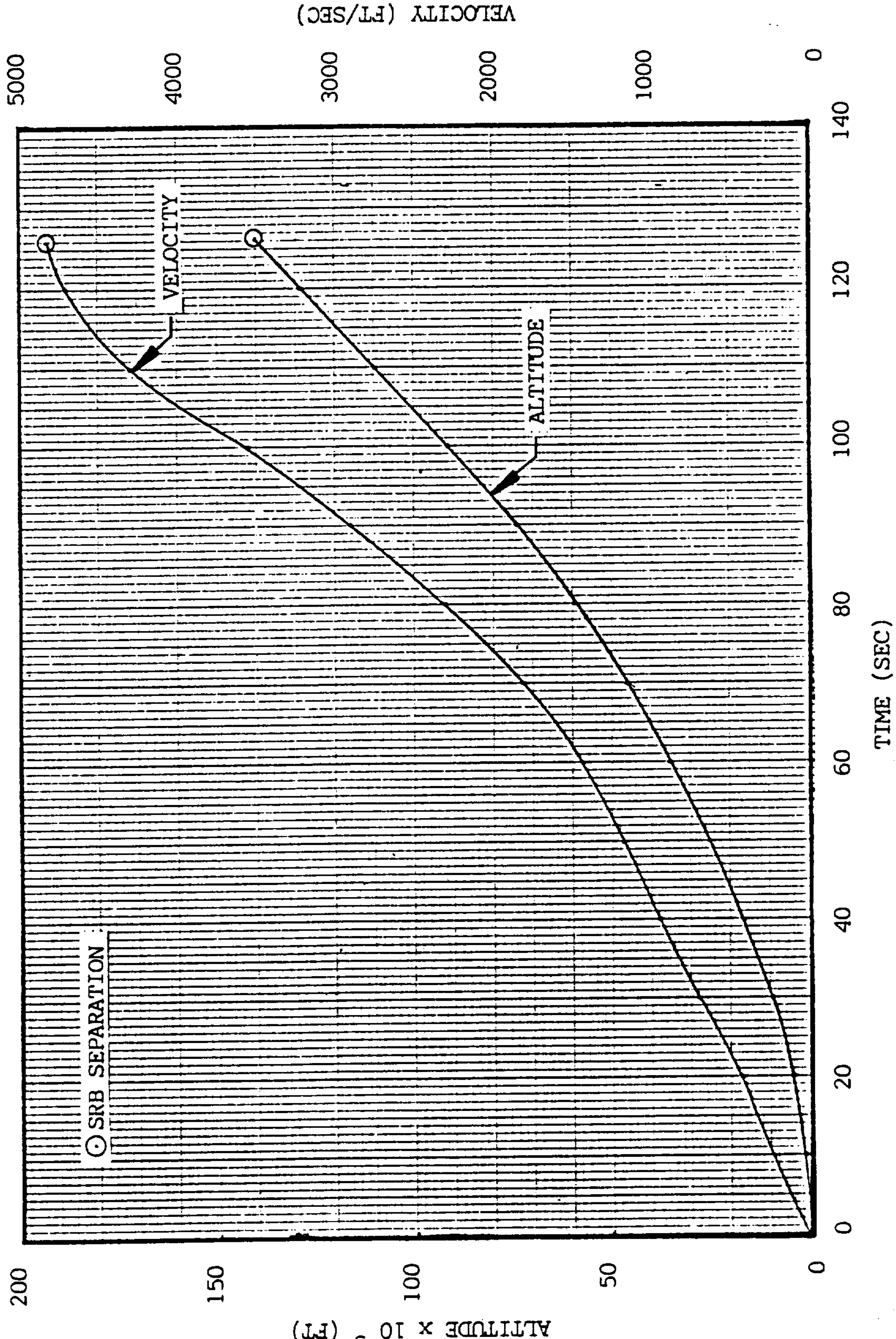


Figure 6: Light V

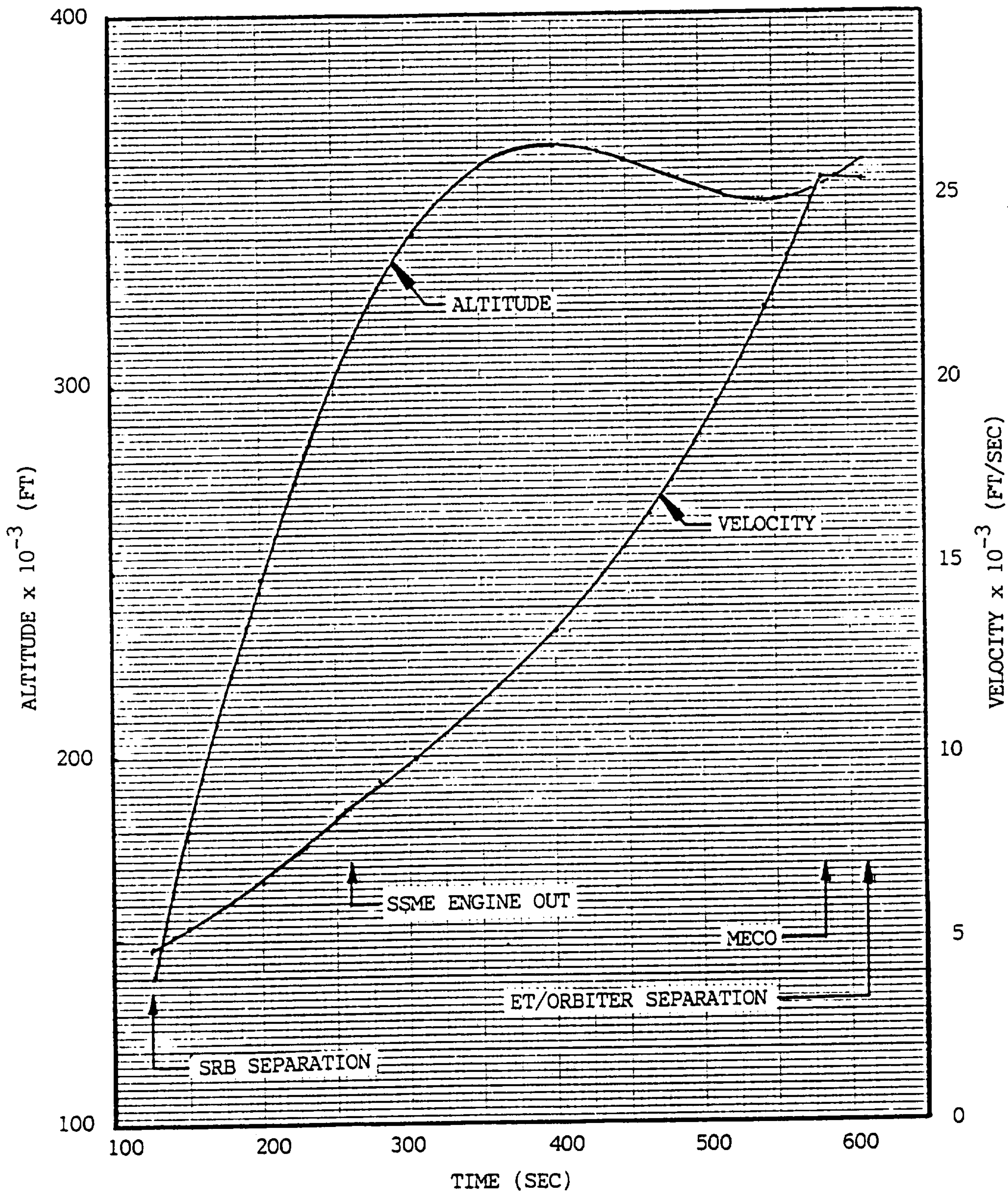


ight External Tank Assembly



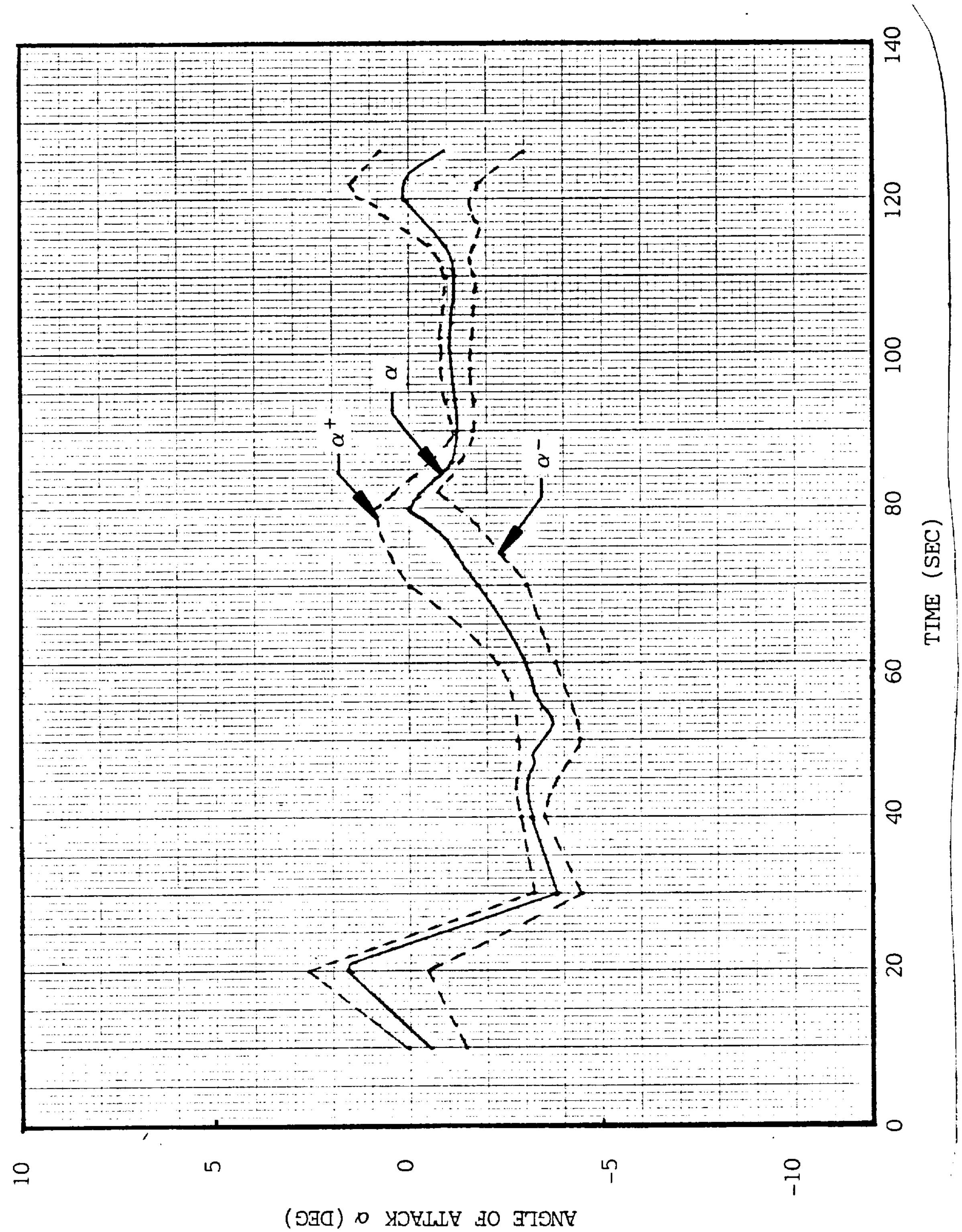
a) First Stage Flight

Figure 7: Light Weight Tank Design Trajectory Altitude/Velocity Profiles



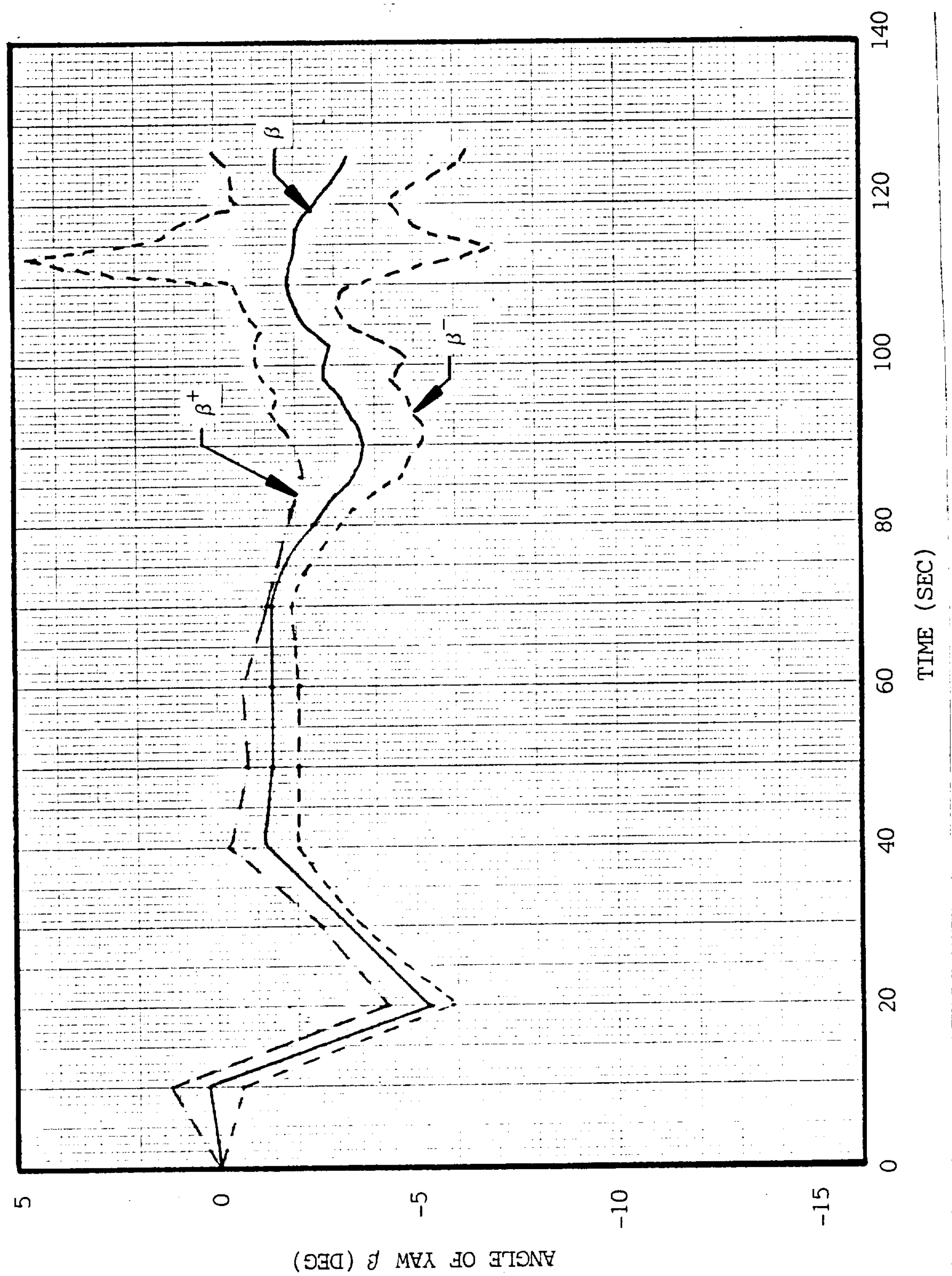
b) Second Stage Flight

Figure 7: Concluded



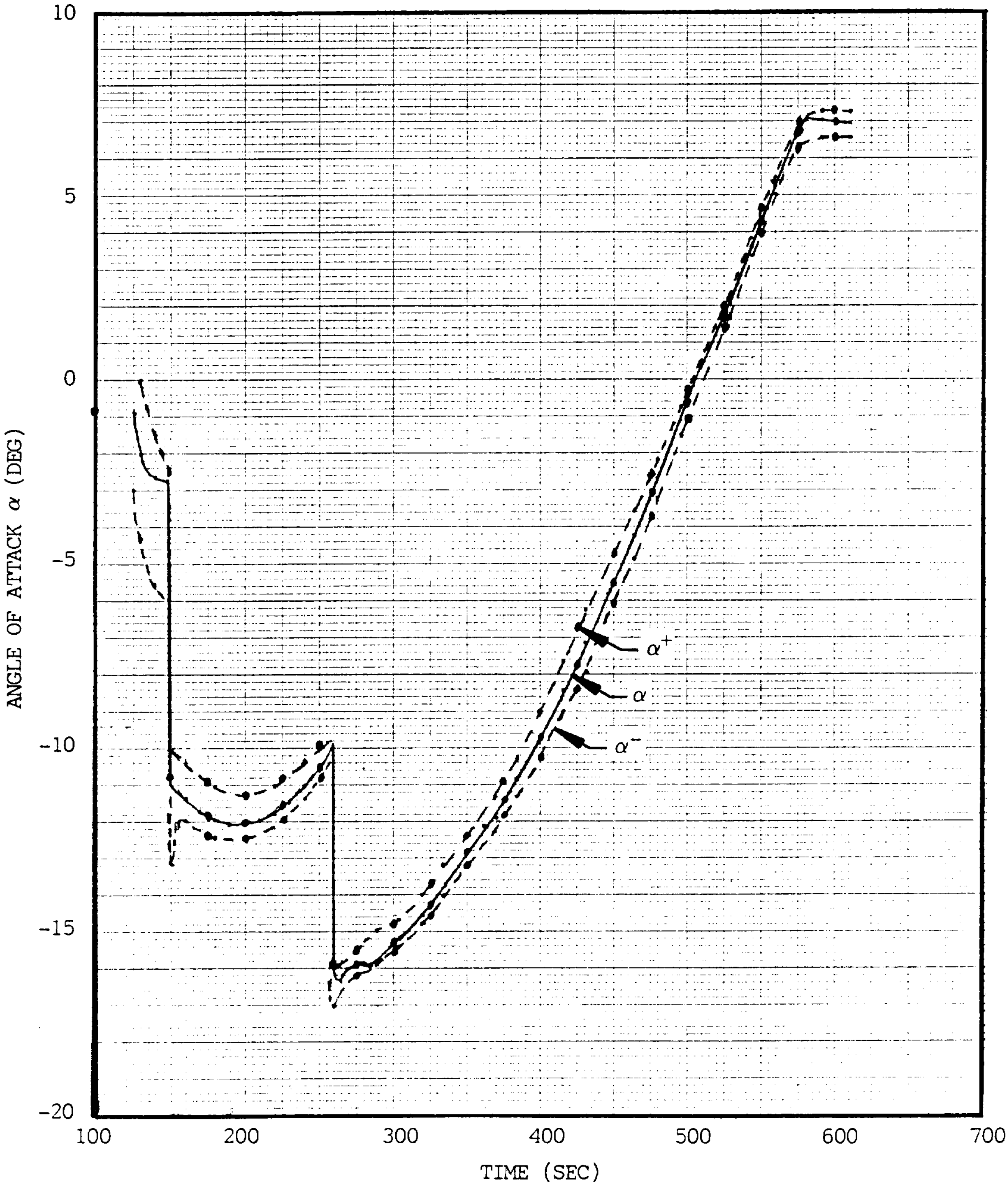
a) Nominal and Dispersed Angles of Attack for First Stage Flight

Figure 8: Light Weight Tank Design Trajectory Angles of Attack and Yaw



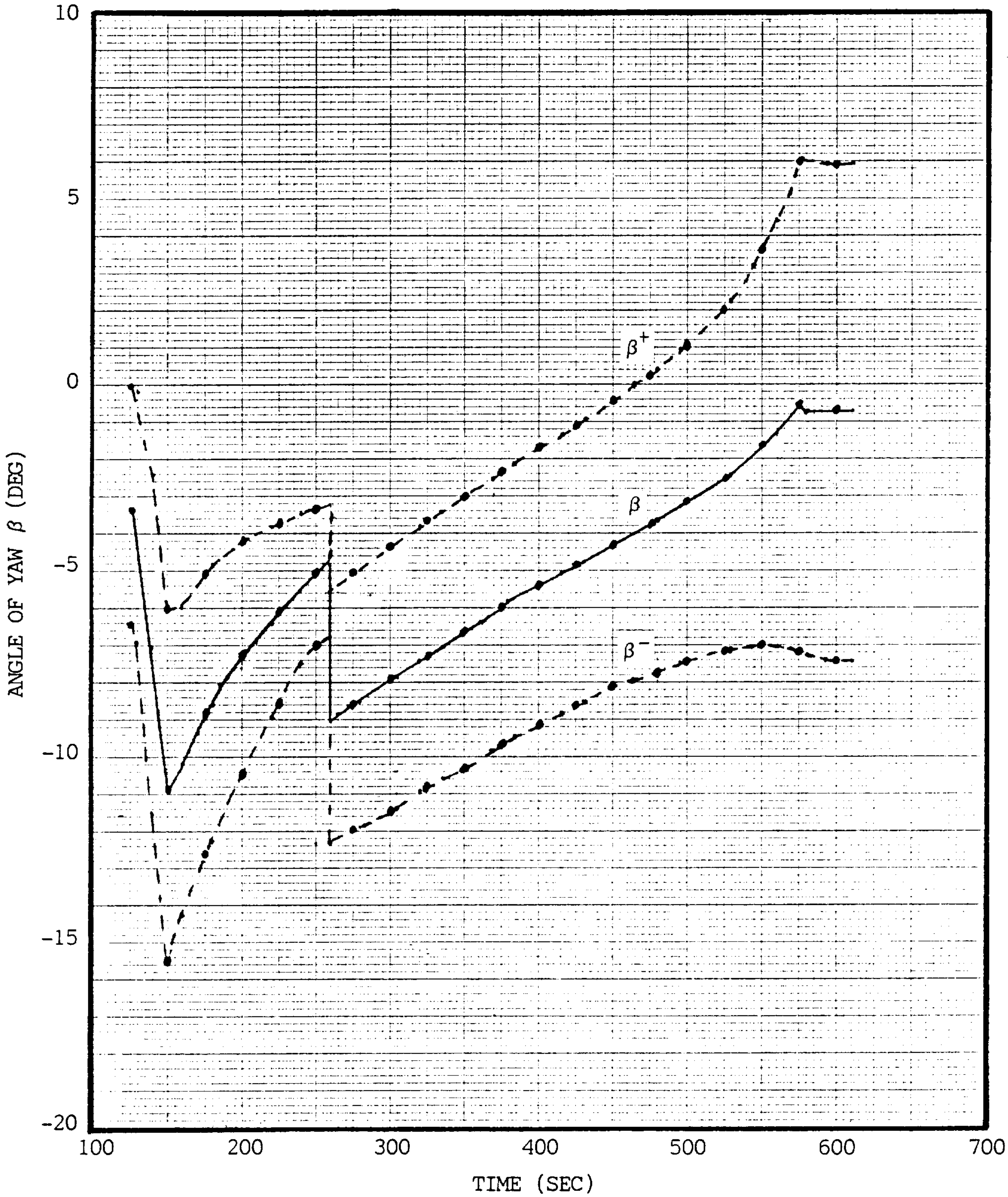
b) Nominal and Dispersed Angles of Yaw for First Stage Flight

Figure 8: Continued



c) Nominal and Dispersed Angles of Attack for Second Stage Flight

Figure 8: Continued



d) Nominal and Dispersed Angles of Yaw for Second Stage Flight

Figure 8: Concluded

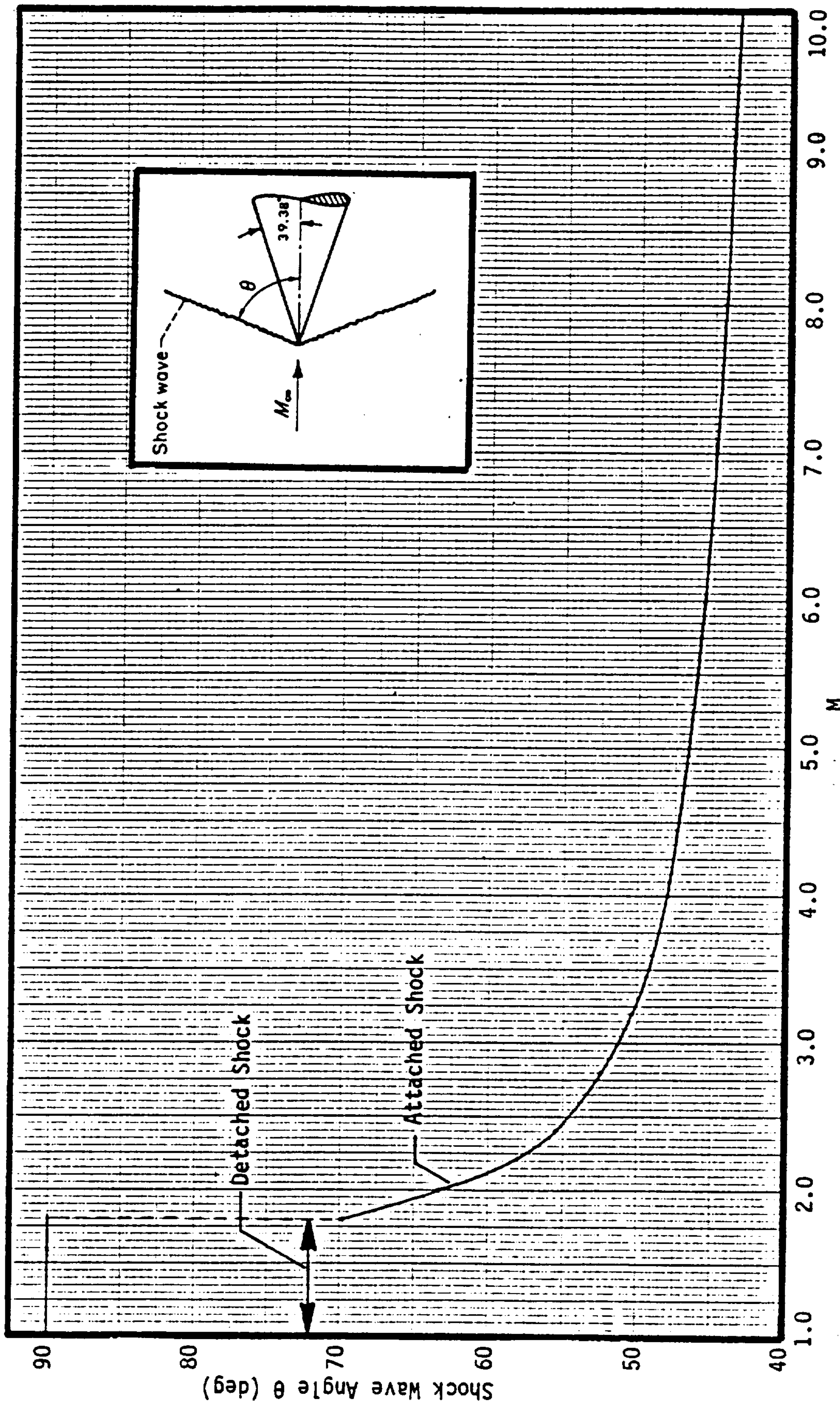


Figure 9: ET Conical Shock Wave Angle as a Function of M_∞

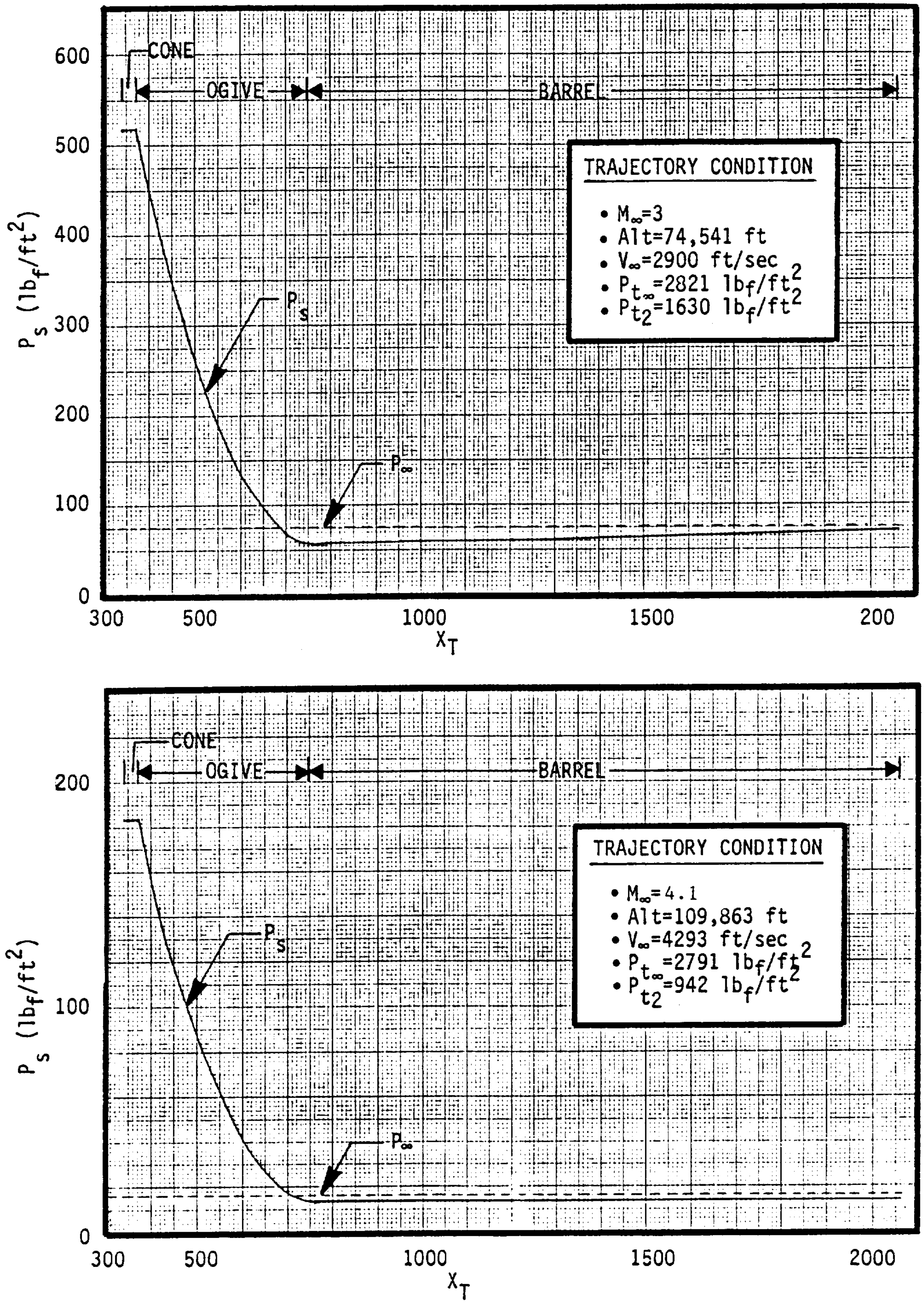


Figure 10: Surface Pressure Distribution on the ET at M = 3.0 and 4.1 for the LWT Design Trajectory

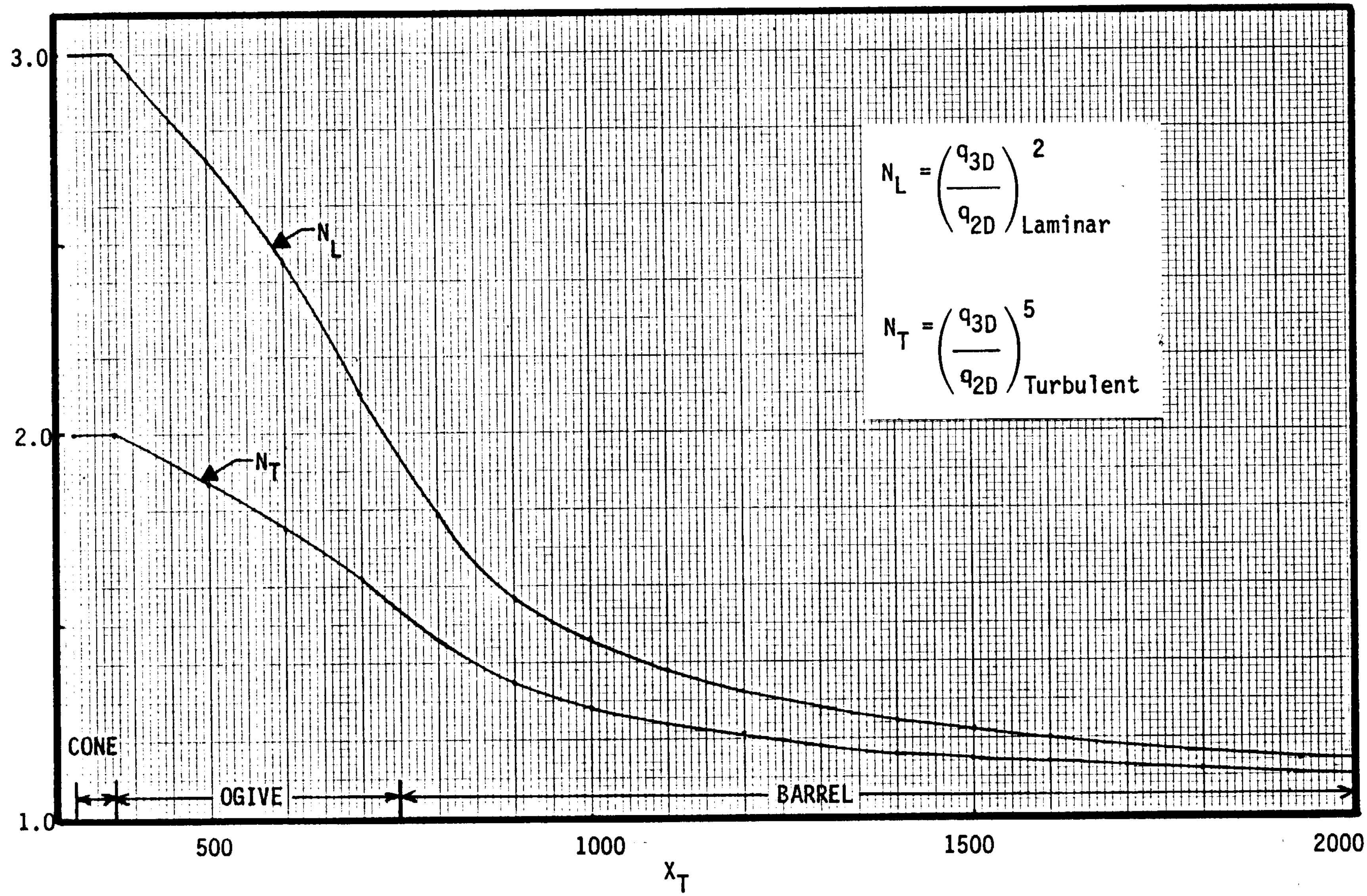


Figure 11: Mangler Factors for Laminar and Turbulent Boundary Layers for the ET

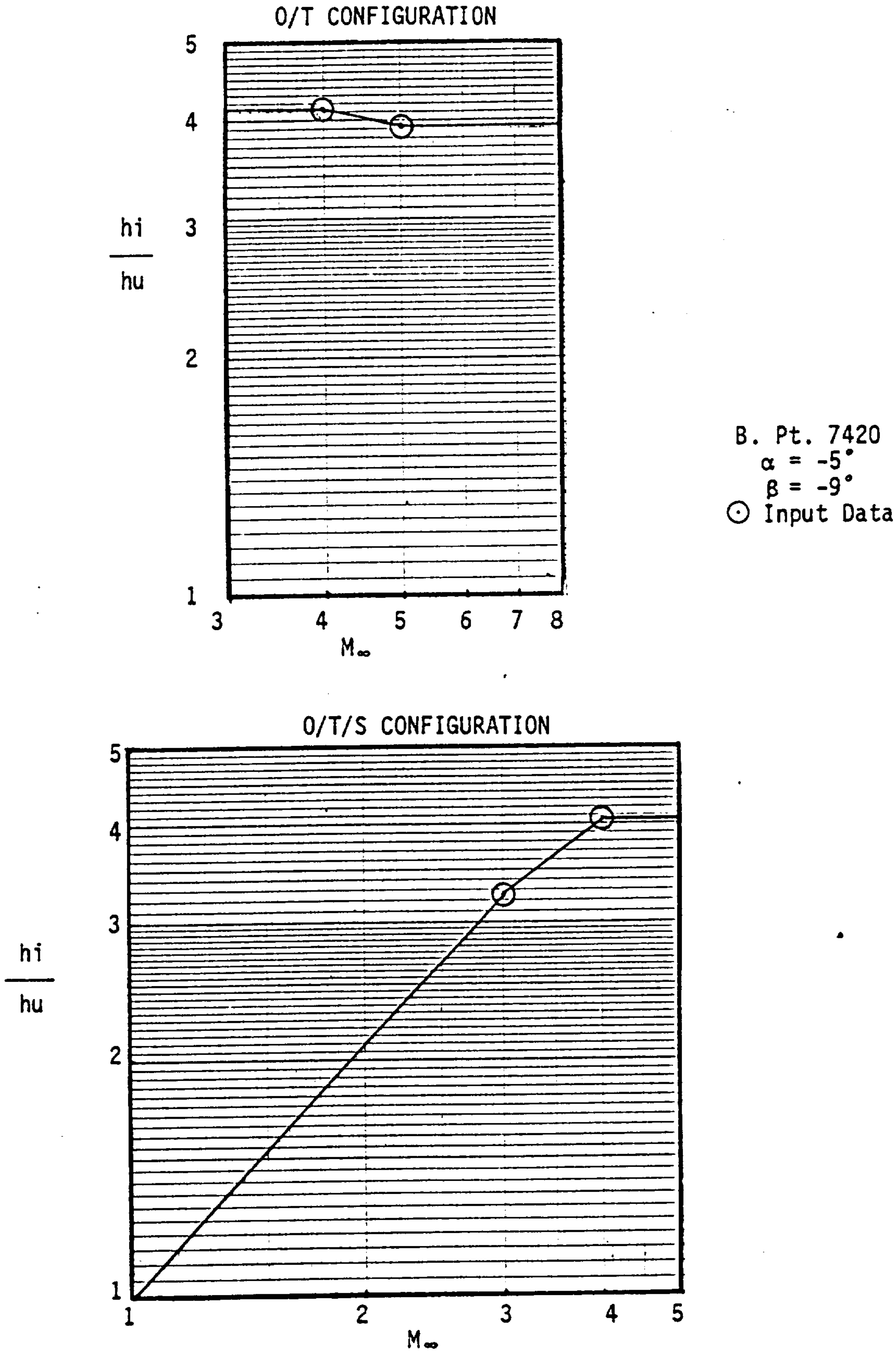


Figure 12: Example of Interpolation/Extrapolation of Hi/Hu for Phase I

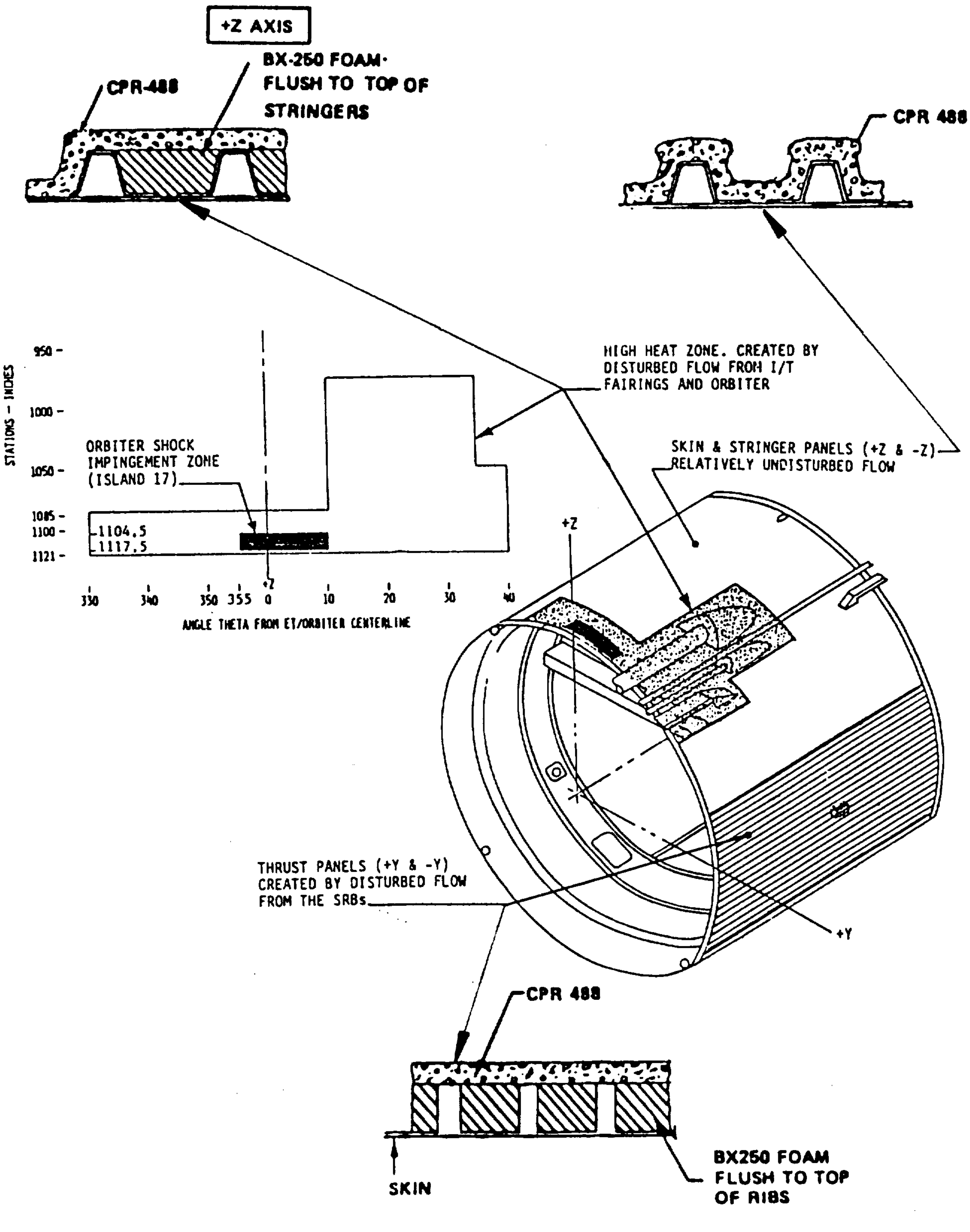
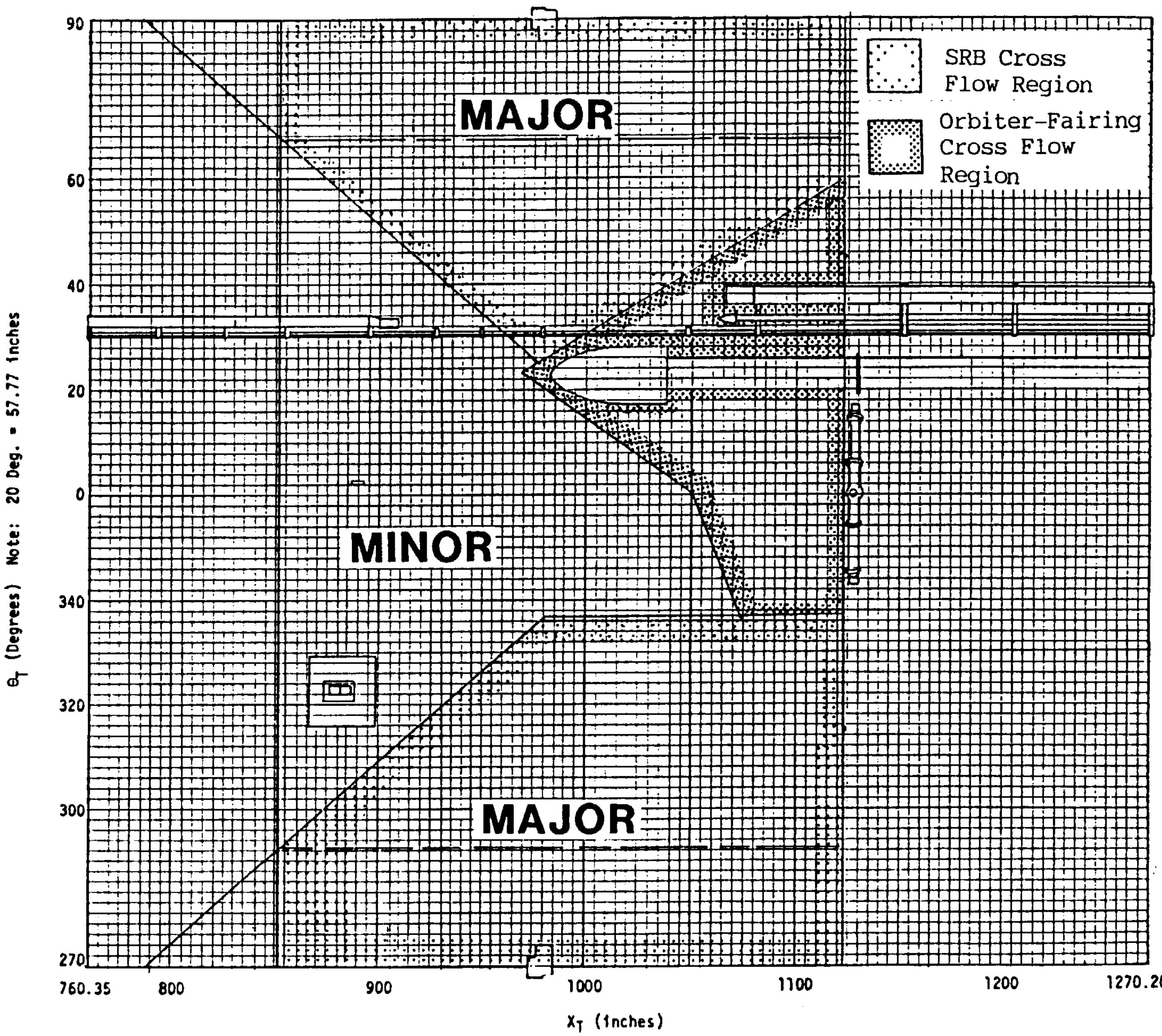
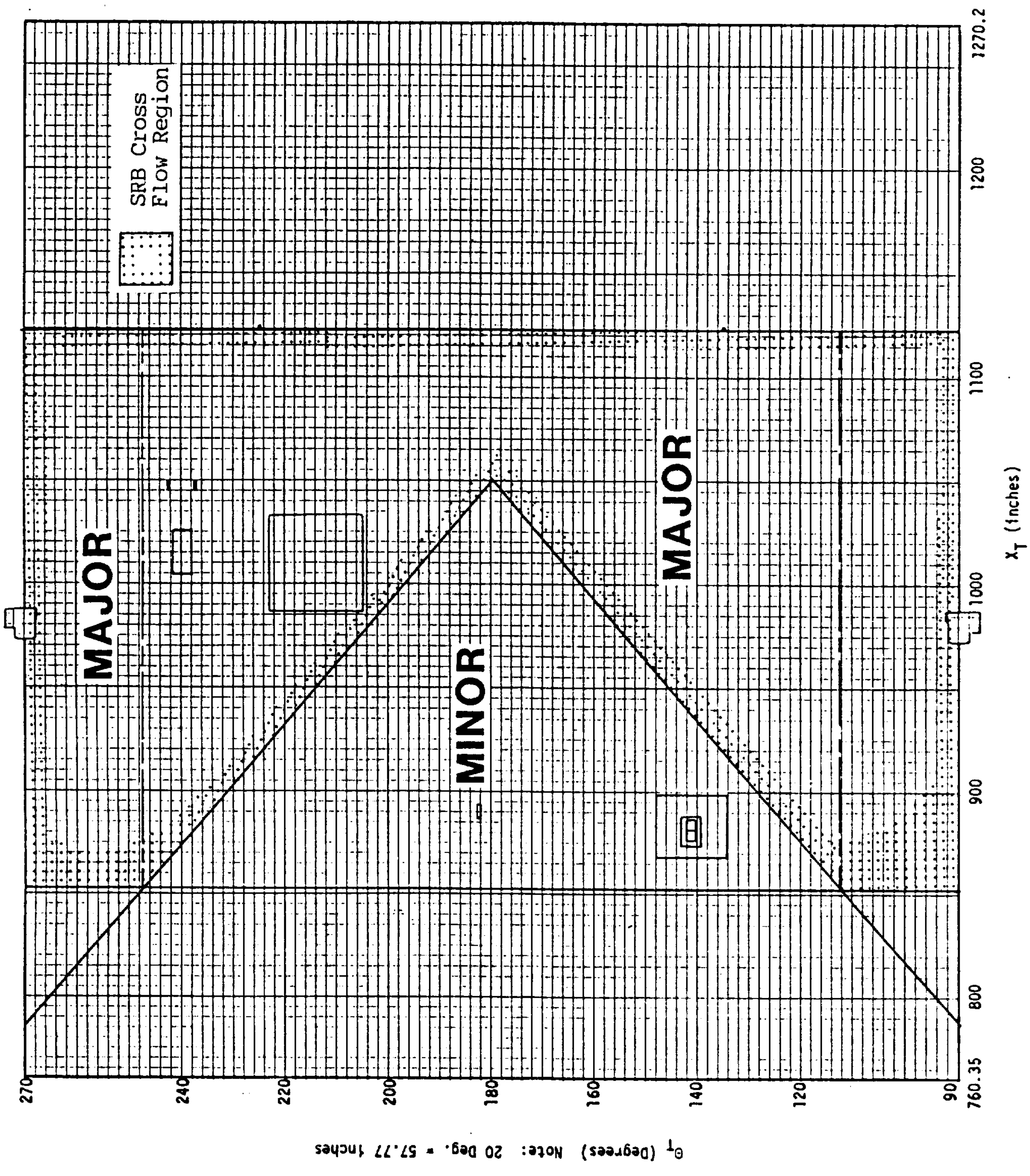


Figure 13: Intertank TPS Design and Surface Finish Details



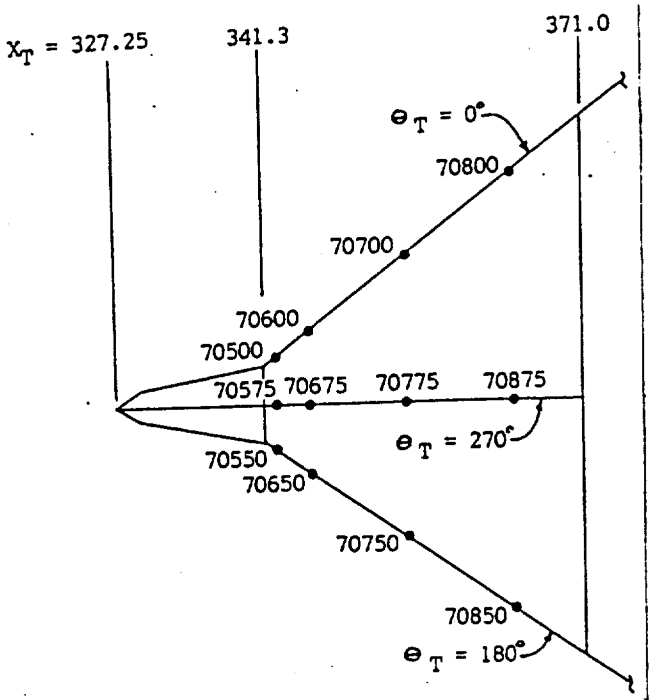
a) ET Top Side Cross Flow Regions

Figure 14: Intertank Crossflow Region Definition



b) ET Bottom Side Cross Flow Regions

Figure 14: Concluded



SYM	θ_T	B. Pt. ID
○	0	70X00
□	180	70X50
△	270	70X75
◊	14	60111
D	8	60112

—— RI
- - - REMTECH

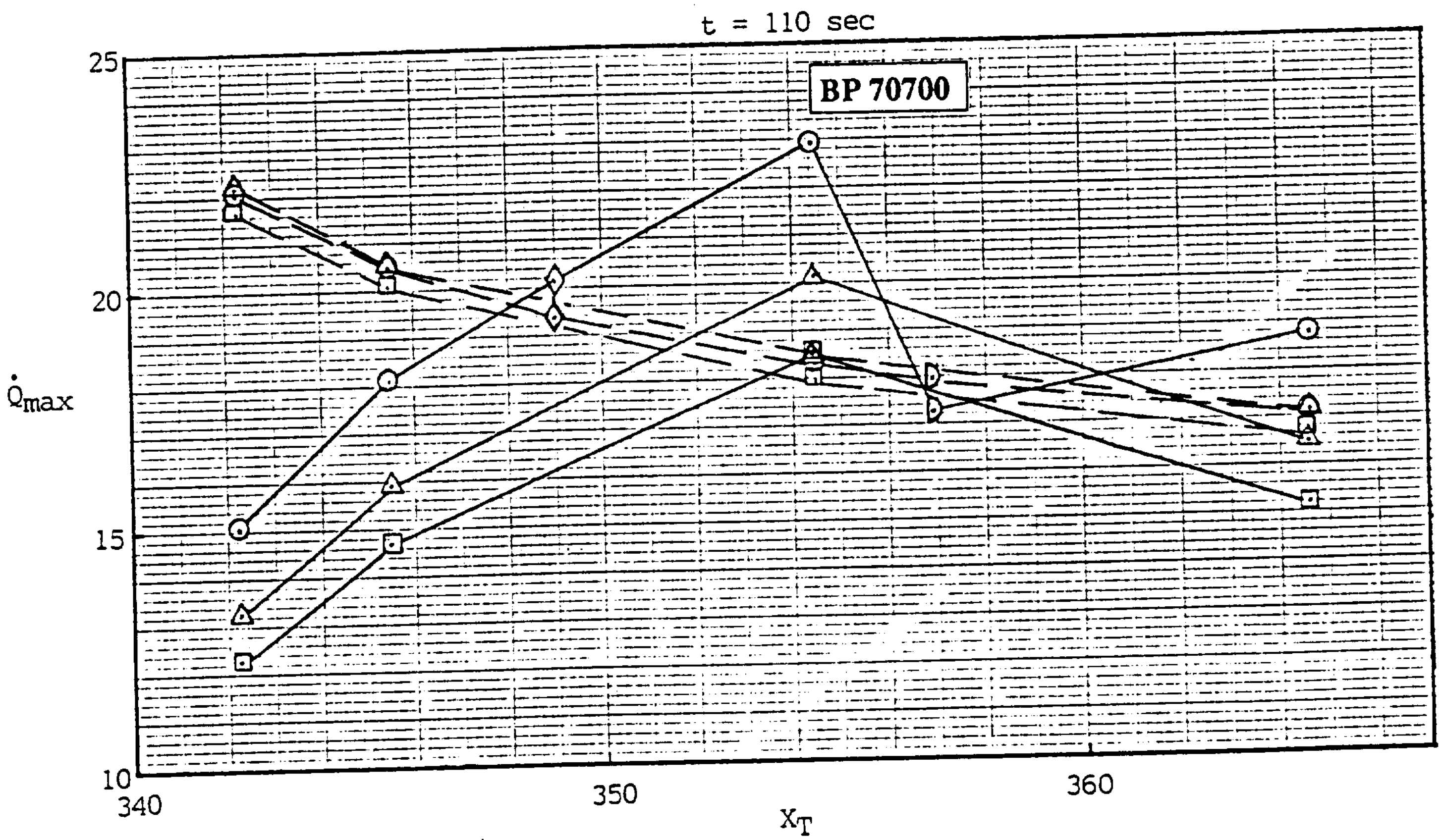
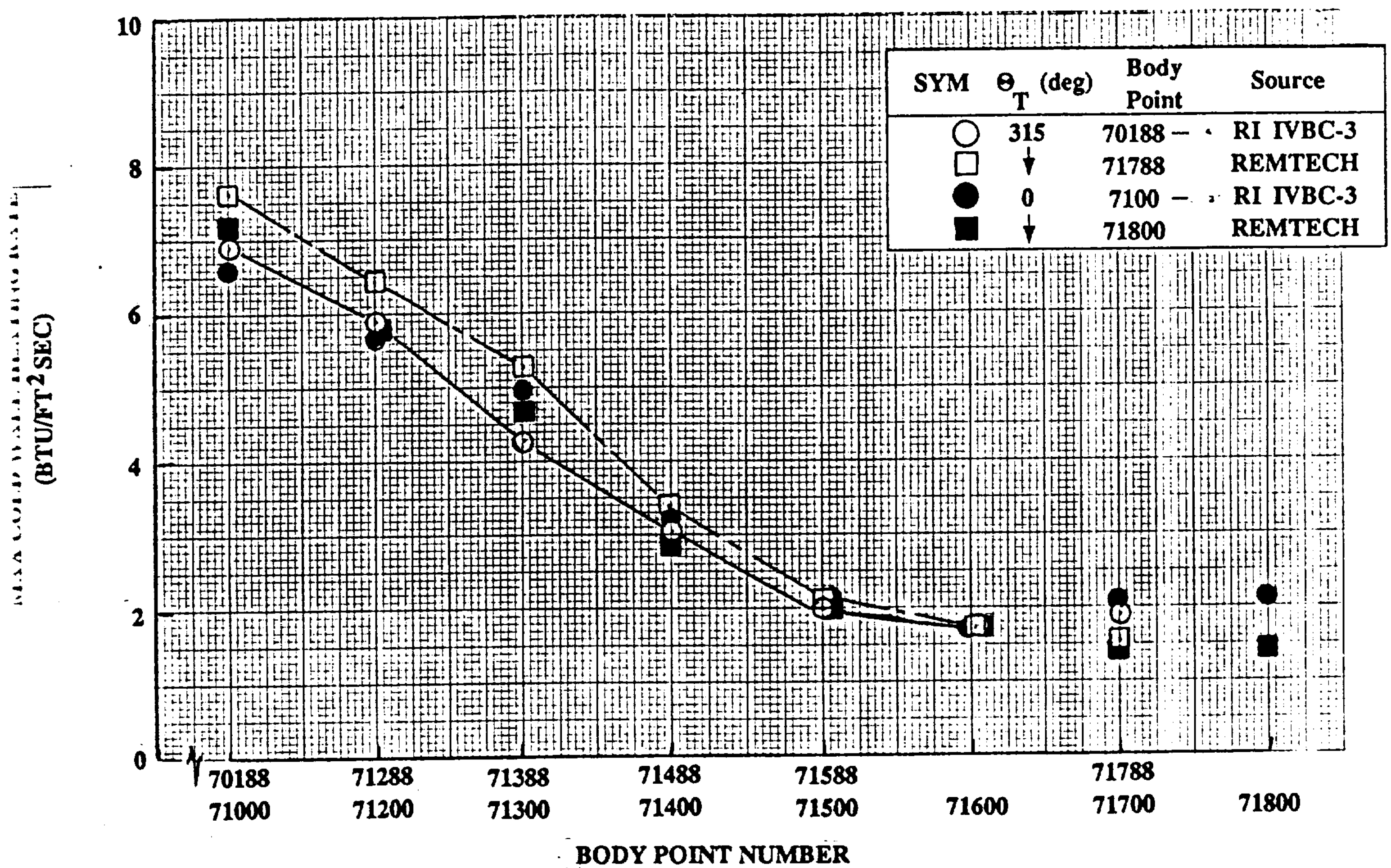
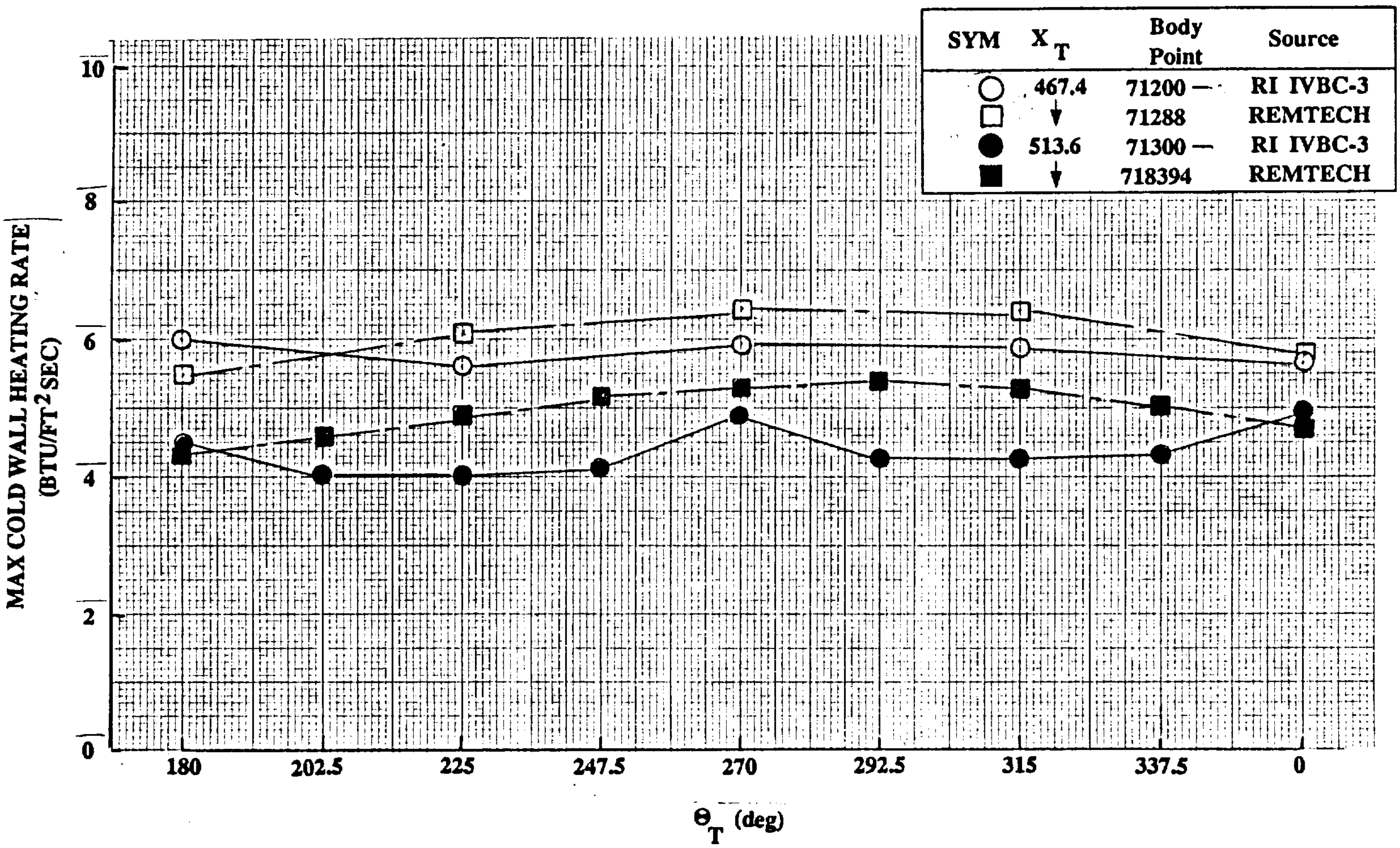


Figure 15: **Comparison of Maximum Heating Rates for Acreage Points on the 40° Cone**



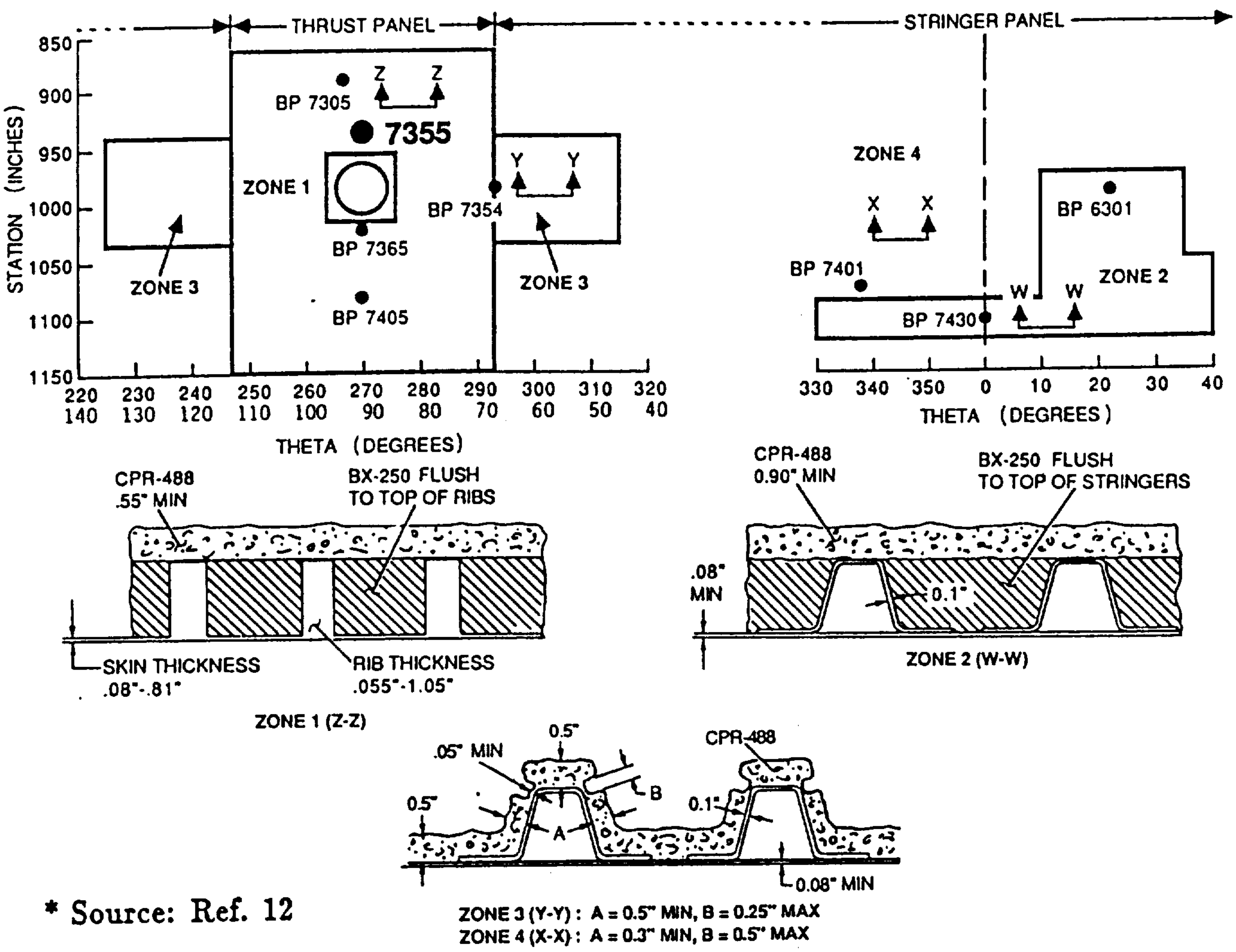
a) Axial Distribution

Figure 16: LO_2 Tank Acreage Heating Environments ($350 \leq X_T \leq 600$)



b) Circumferential Distribution

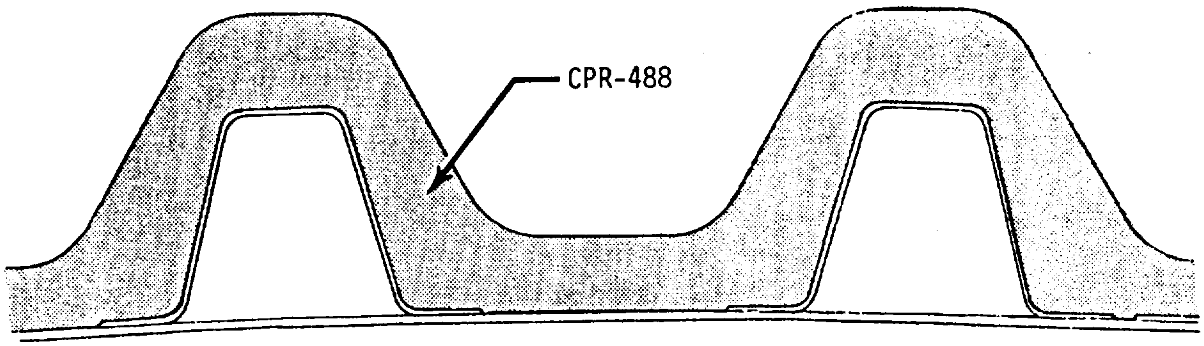
Figure 16 Concluded



* Source: Ref. 12

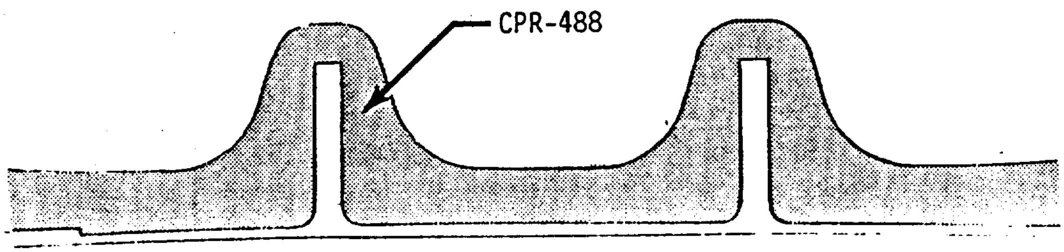
a) LWT 16 - 43

Figure 17: Intertank TPS Configuration



ZONE	CPR THICKNESS
A	0.75
B	0.50
C	0.30
D	0.40
E	0.90

STRINGER PANEL



ZONE	CPR THICKNESS
A	0.75
B	0.50
C	0.30

THRUST PANEL

* Source: Ref. 12

b) Intertank Minimum TPS Requirement Assuming Uniform Spray (44 & Up)

Figure 17 Concluded

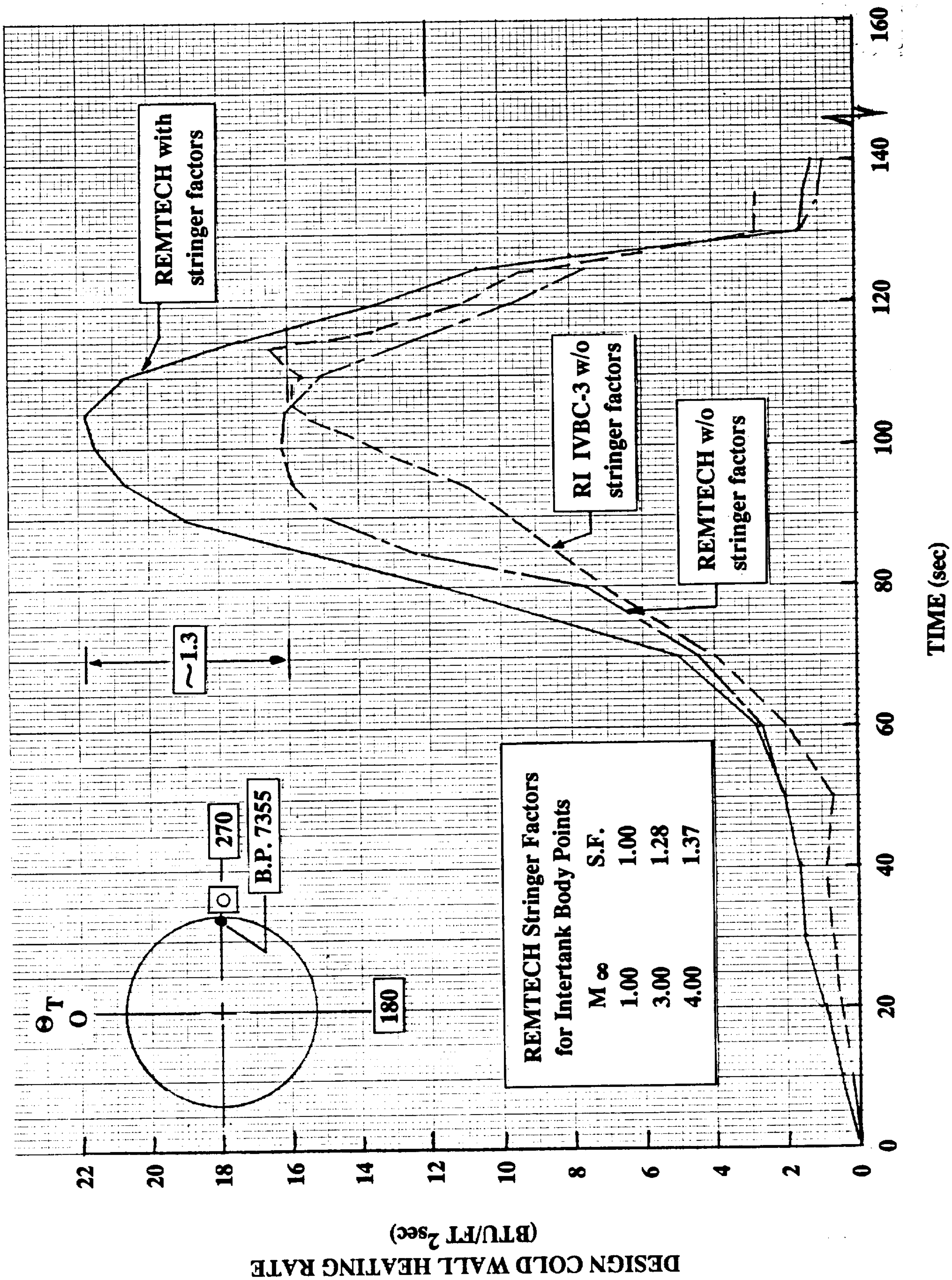
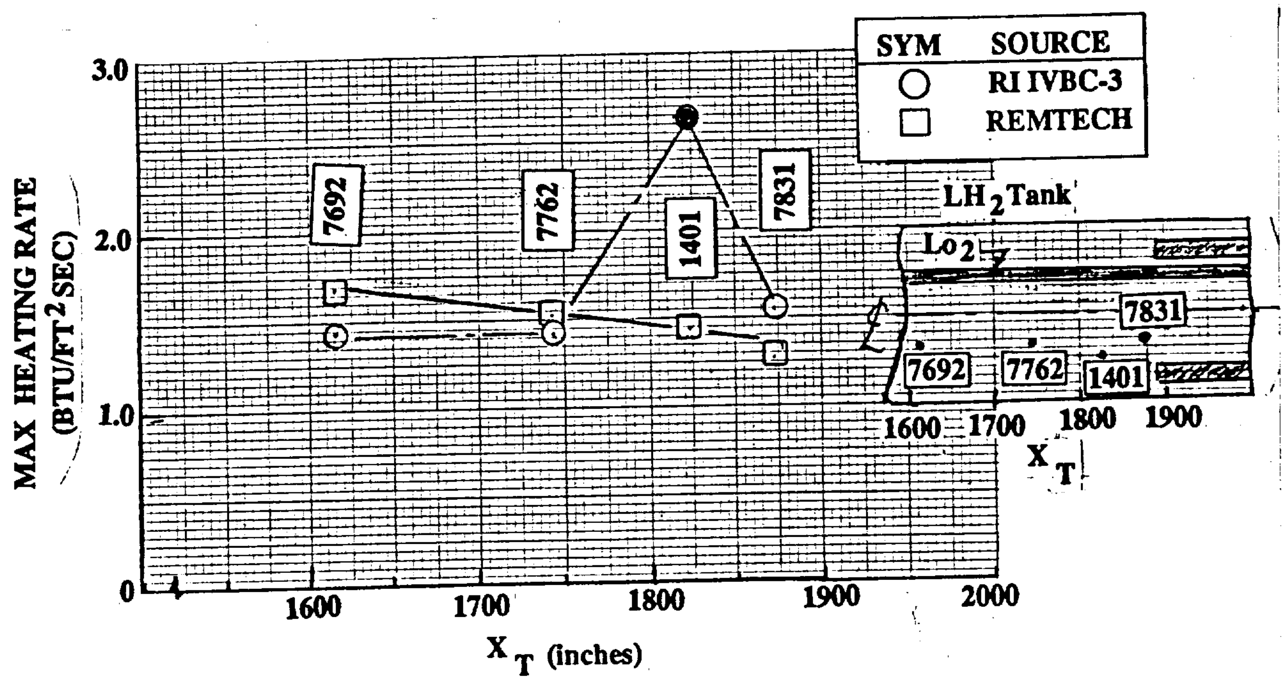
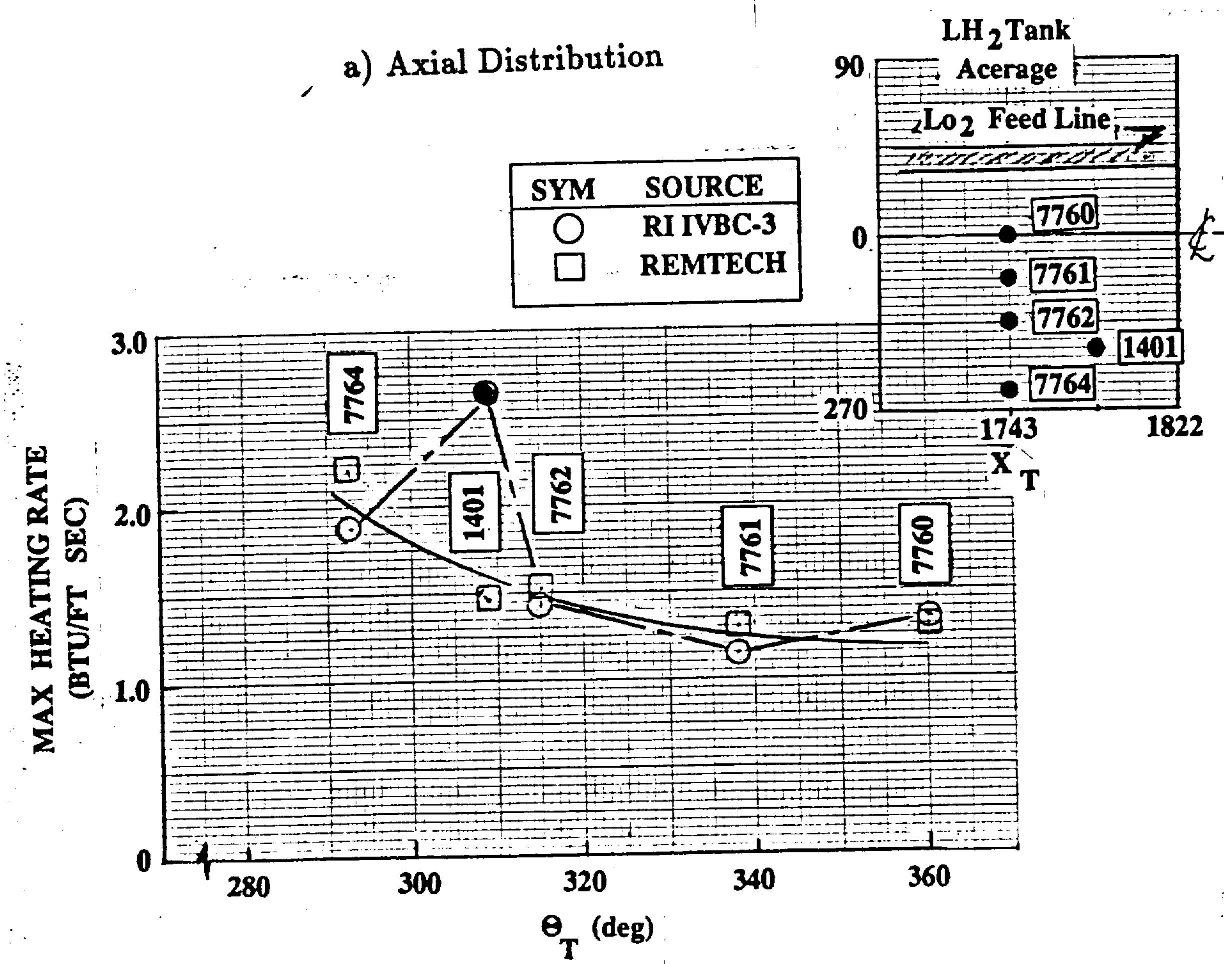


Figure 18: Intertank Design Environments for B.P. 7355

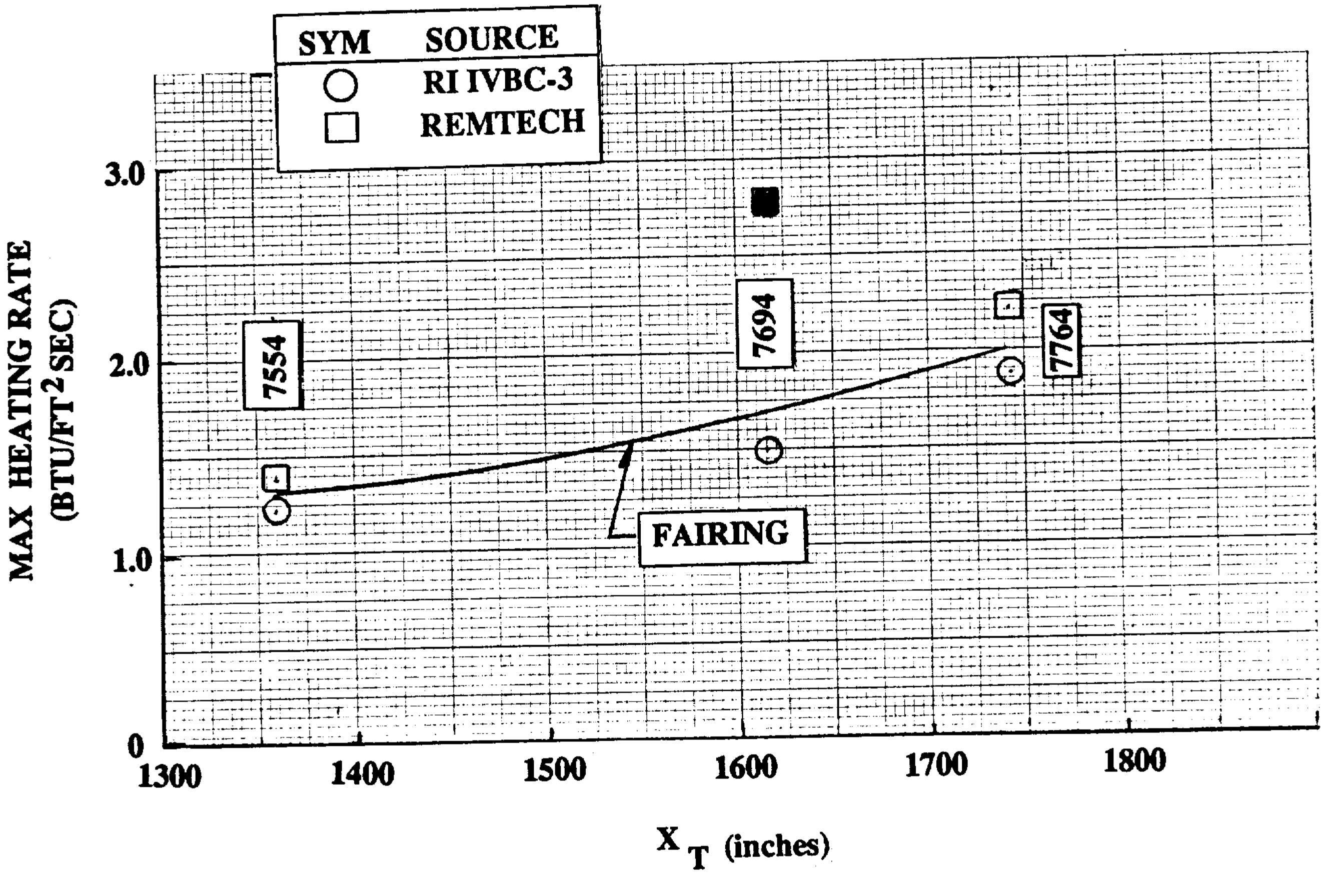


a) Axial Distribution

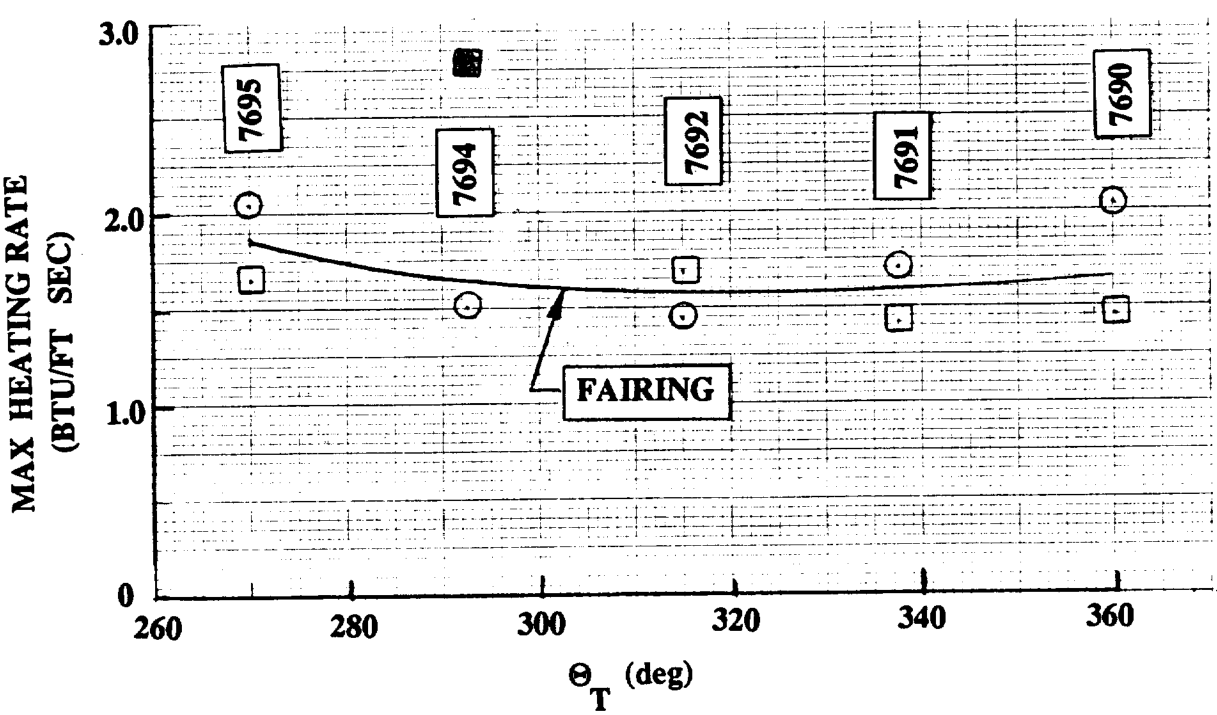


b) Circumferential Distribution

Figure 19: LH_2 Tank Acreage Heating Environments in the Vicinity of B.P. 1401

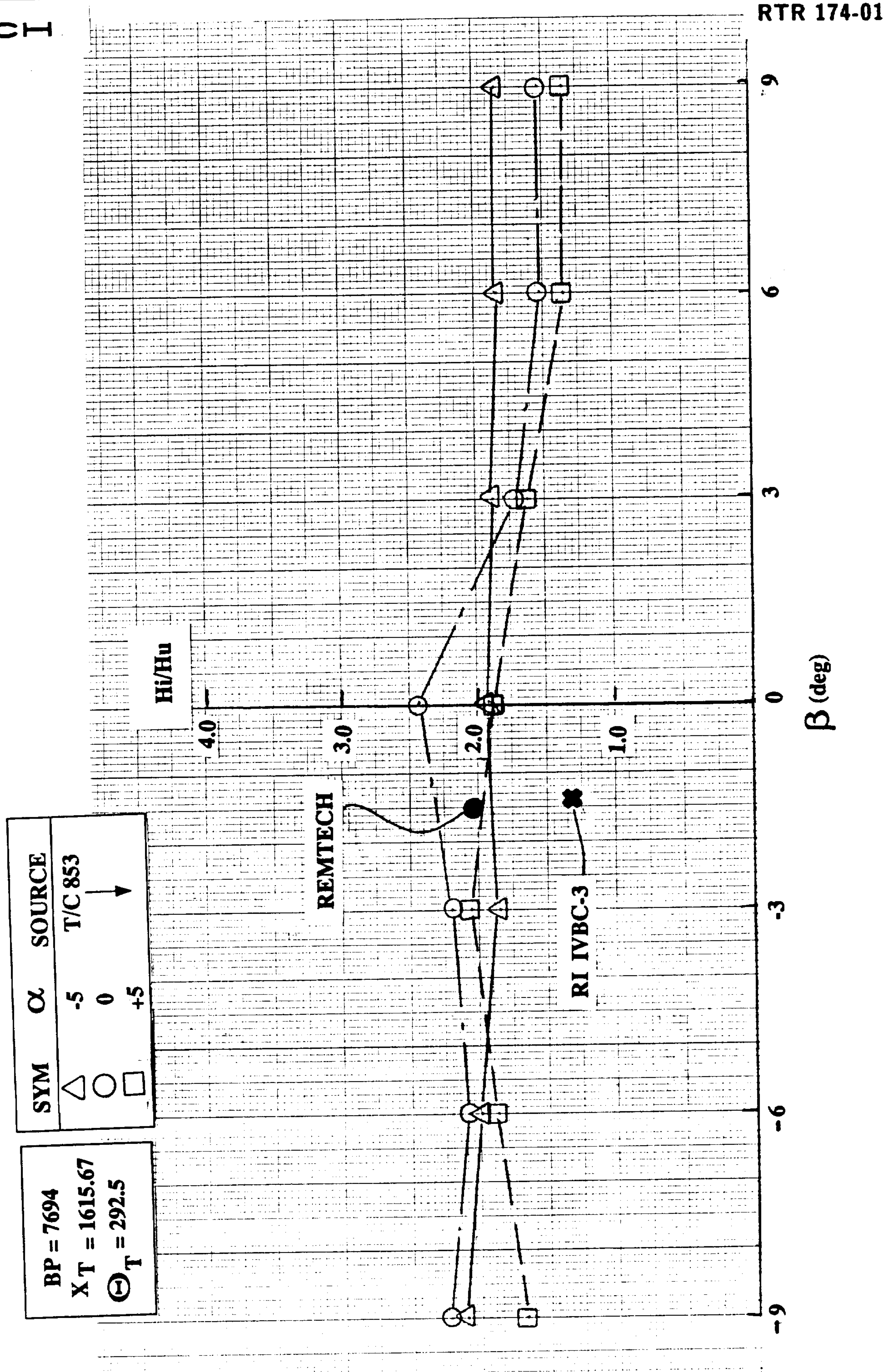


a) Axial Distribution



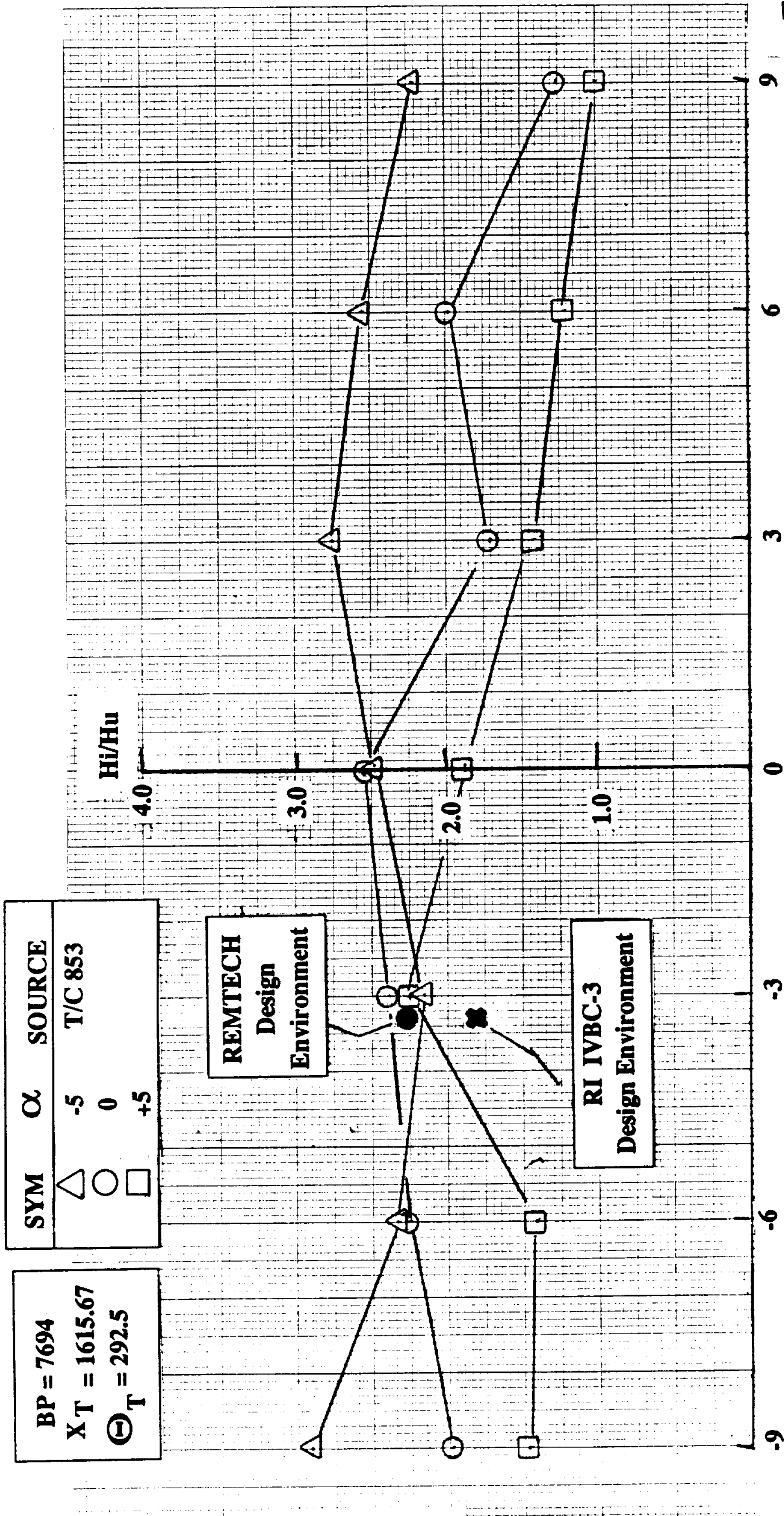
b) Circumferential Distribution

Figure 20: Maximum Heating Rates in the Vicinity of B.P. 7694



a) M = 3.00

Figure 21: Hi/Hu Data Base for B.P. 7694



b) M = 4.00

Figure 21 Concluded

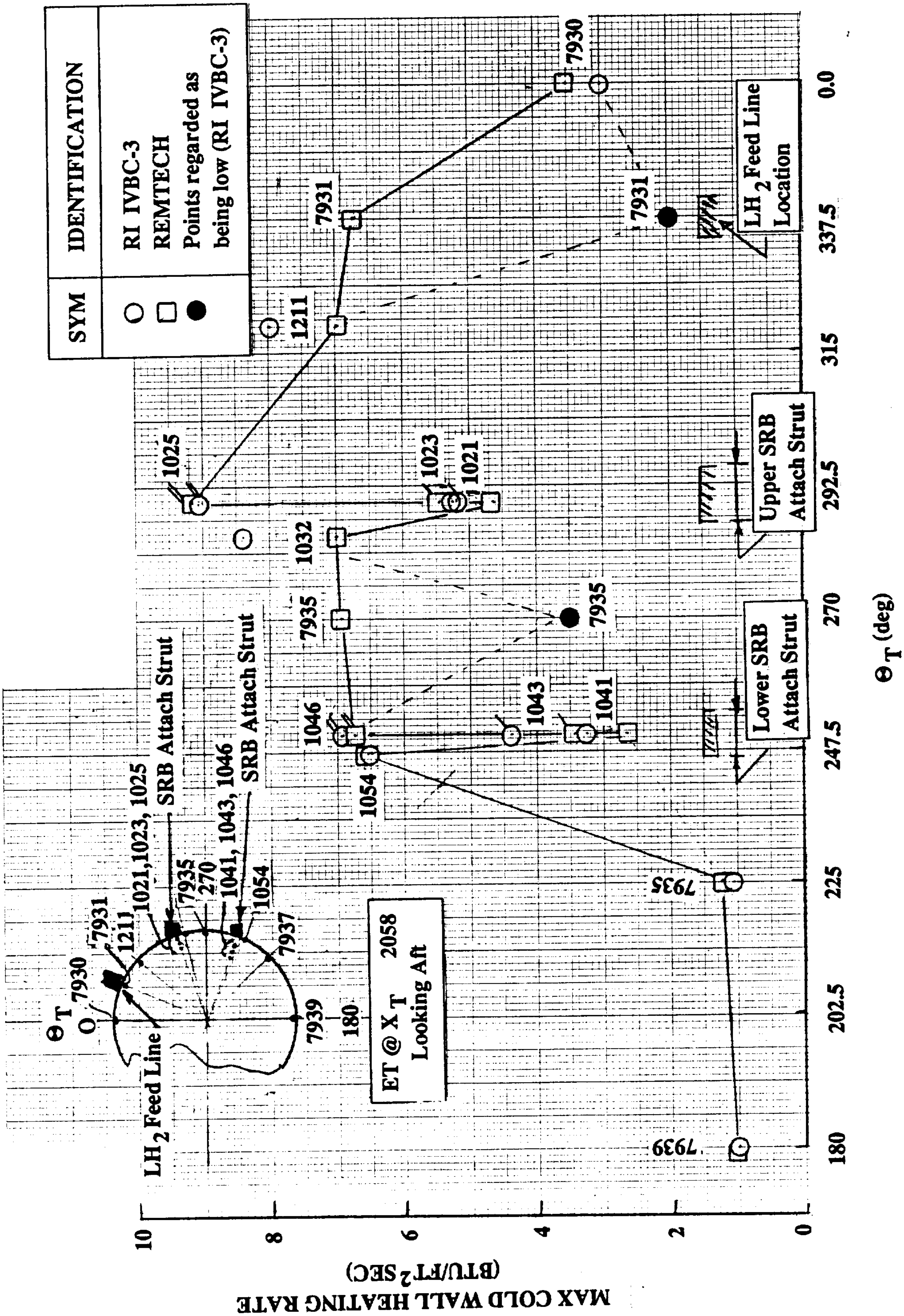
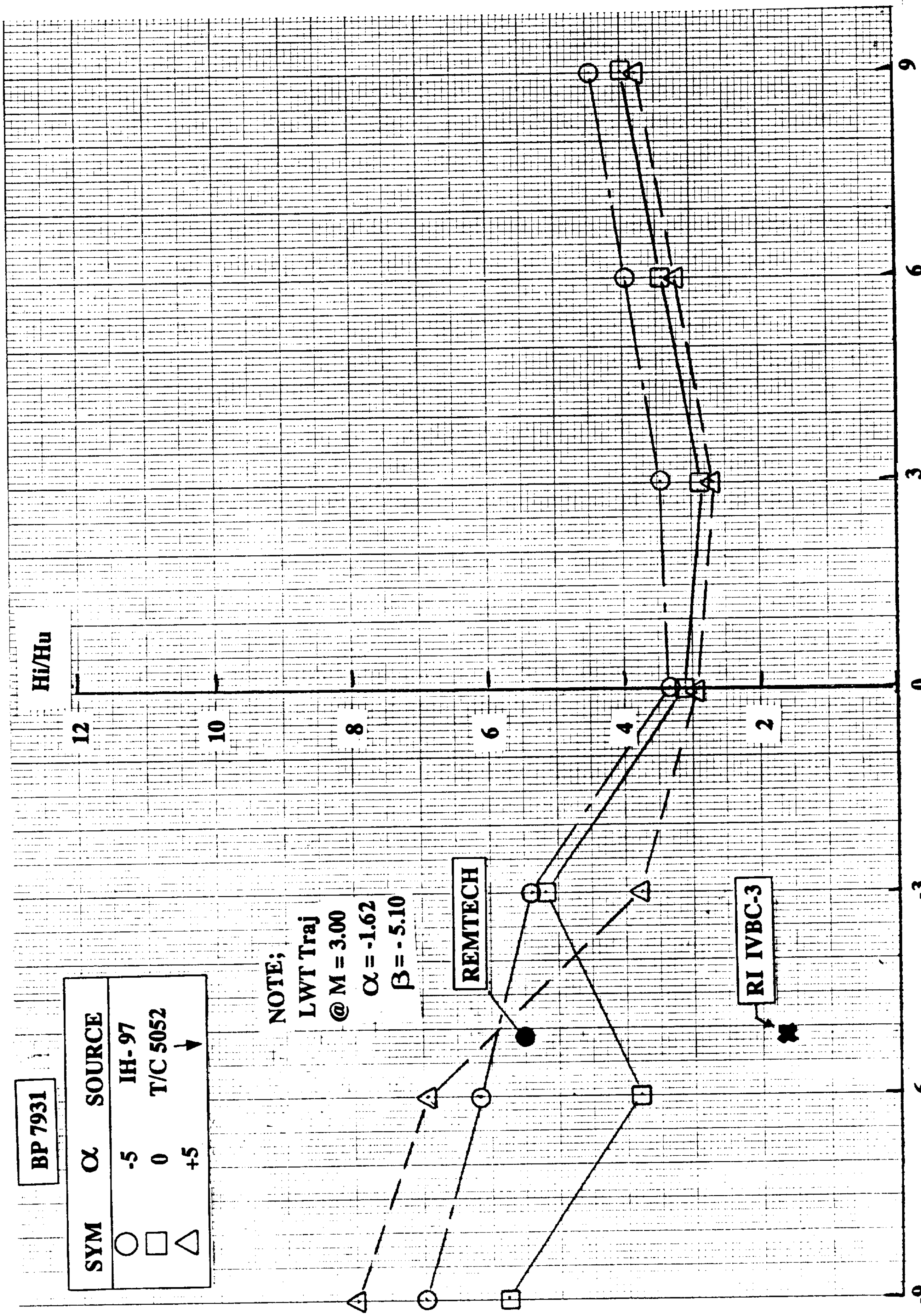
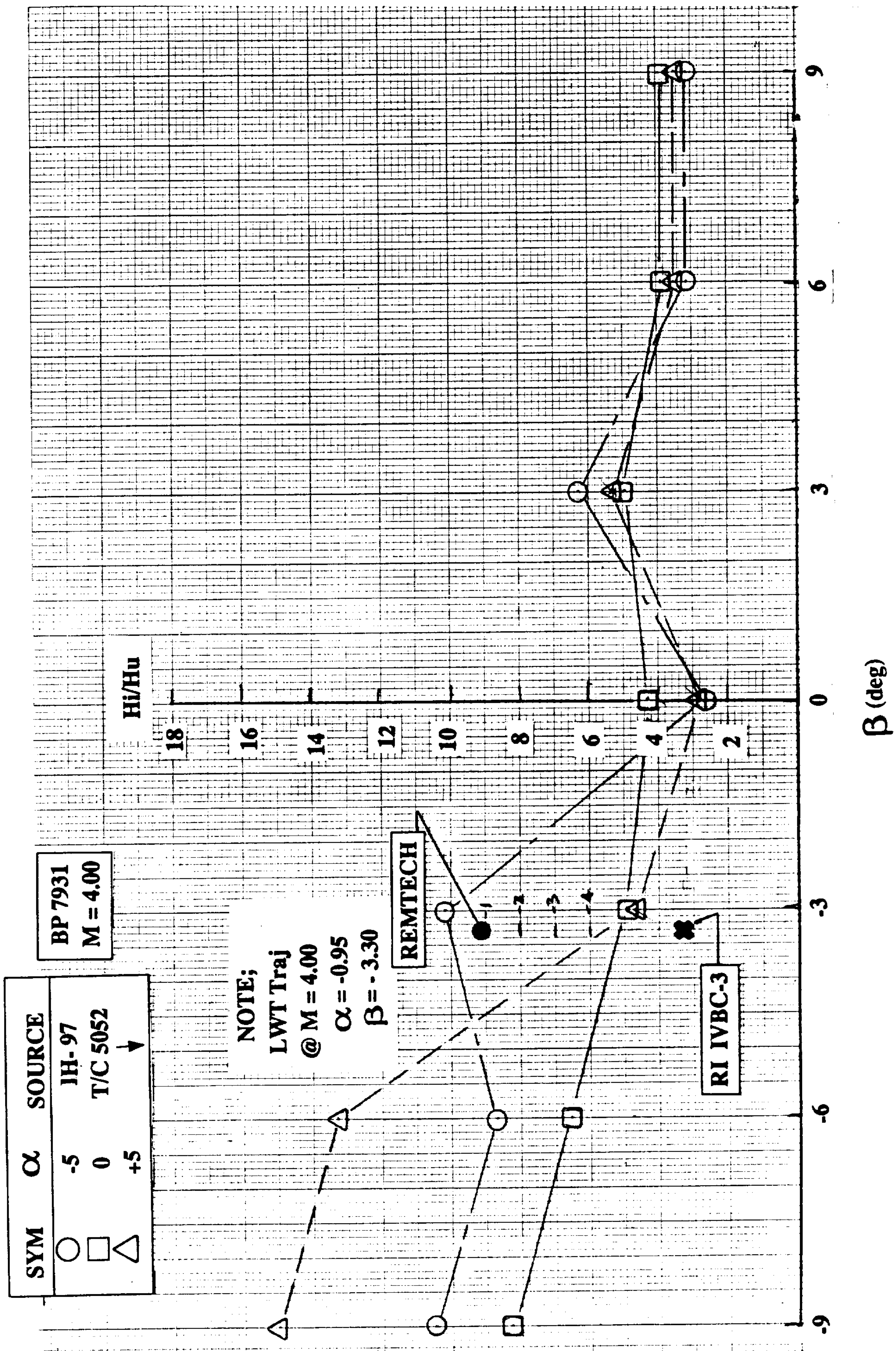


Figure 22: Circumferential Heating Distribution in the Vicinity of B.P. 7931 and 7935 ($X_T \sim 2058$)



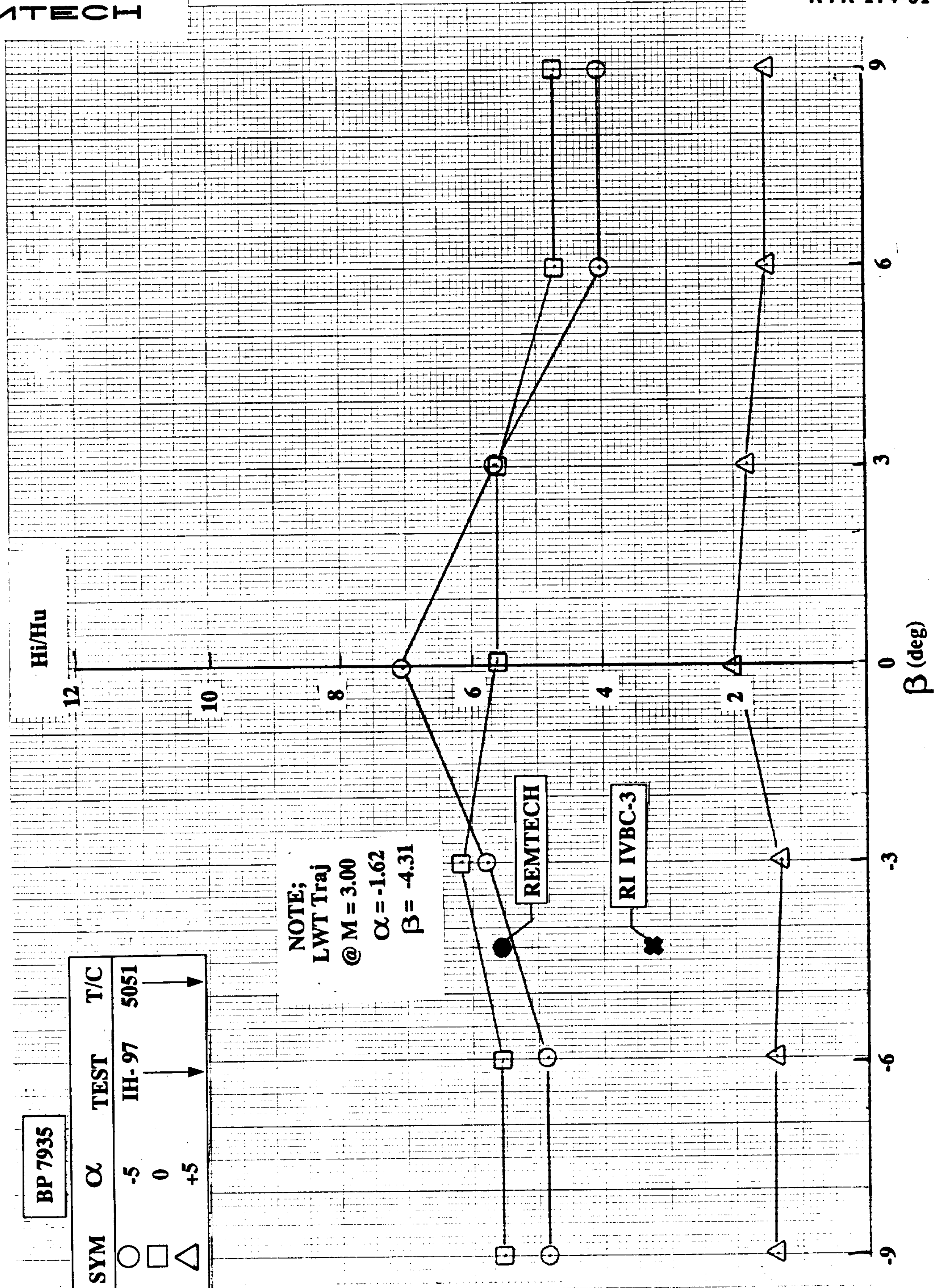
a) M = 3.00

Figure 23: Hi/Hu Data Comparison for B.P. 7931



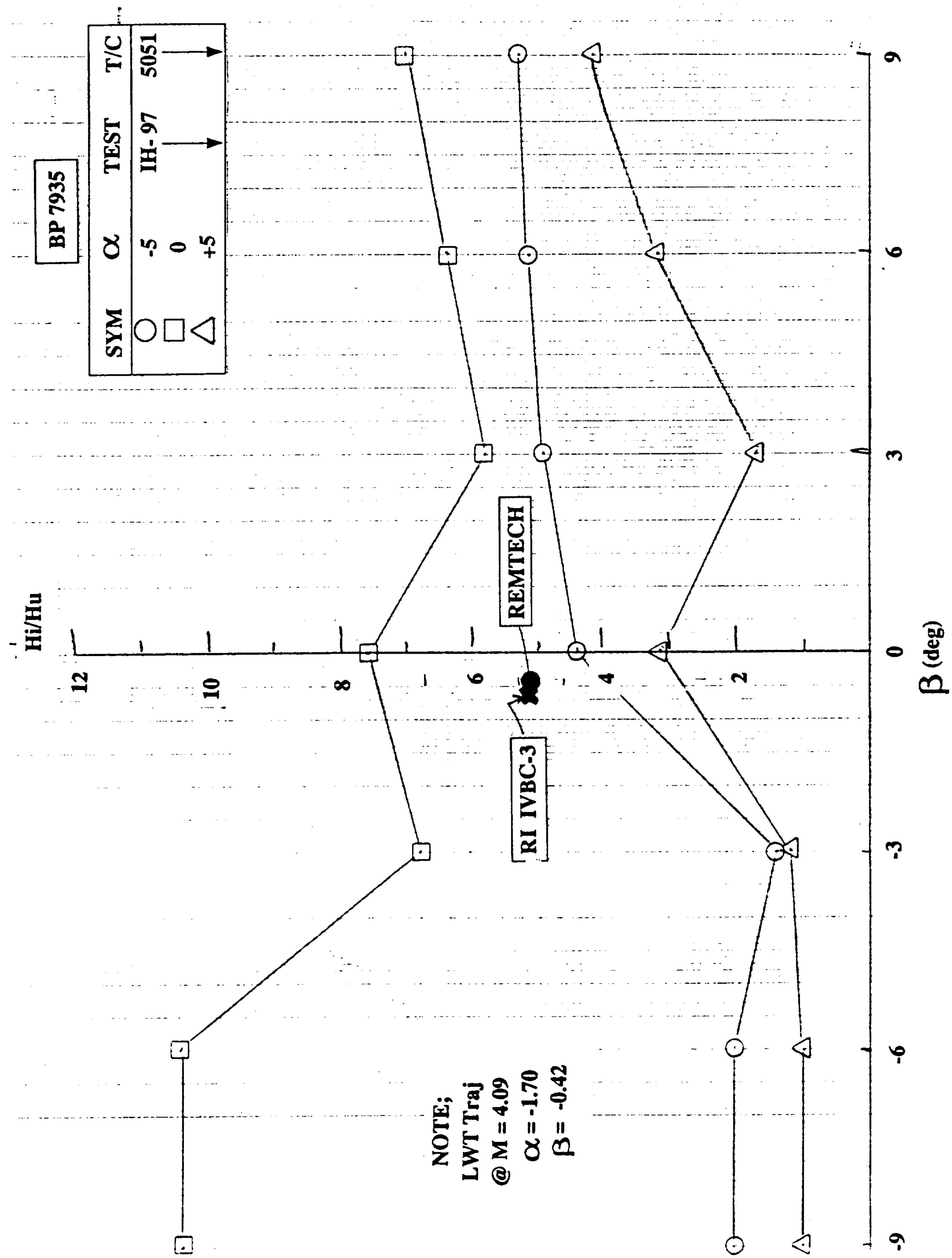
b) M = 4.00

Figure 23 Concluded



a) M = 3.00

Figure 24: Hi/Hu Data Comparison for B.P. 7935



b) M = 4.00

Figure 24 Concluded

Table 1: 10°/30° Nose Spike and 40° Nose Cone Body Point Locations

BODY PT	COORDINATES		LOCATION
	X_T (in)	θ_T (deg)	
60133	327.66	0.0	30° Conical Nose Tip
60101	328.00	0.0	
60122	328.00	180.0	
70300	329.00	0.0	
70350	329.00	180.0	
70375	329.00	270.0	
70400	335.00	0.0	10° Nose Cone
70450	335.00	180.0	
70475	335.00	270.0	
60130	338.00	0.0	
70500	342.24	0.0	40° Cone
70550	342.24	180.0	
70575	342.24	270.0	
70600	345.50	0.0	
70650	345.50	180.0	
70675	345.50	270.0	
60111	349.00	14.0	
70700	354.50	0.0	
70750	354.50	180.0	
70775	354.50	270.0	
60112	357.00	8.0	
70800	364.50	0.0	
70850	364.50	180.0	
70875	364.50	270.0	

Table 2: LO_2 Tank Body Point Locations

BODY PT	COORDINATES		LOCATION
	X_T (in)	θ_T (deg)	
70900	375.10	0.0	LO_2 Tank Acreage
70950	375.10	180.0	
70956	375.10	202.5	
70963	375.10	225.0	
70969	375.10	247.5	
70975	375.10	270.0	
70981	375.10	292.5	
70988	375.10	315.0	
70994	375.10	337.5	
60400	402.50	357.4	
60405	402.50	16.9	
60407	402.50	24.3	
60409	402.50	31.5	
60411	402.50	38.7	
60413	402.50	46.1	
60418	402.50	65.6	
60500	409.90	0.1	
60507	409.90	24.9	
60509	409.90	31.5	
60510	409.90	38.1	
60517	409.90	62.9	
71000	421.30	0.0	
71050	421.30	180.0	
71056	421.30	202.5	
71063	421.30	225.0	
71069	421.30	247.5	
71075	421.30	270.0	
71081	421.30	292.5	
71088	421.30	315.0	
71094	421.30	337.5	
60601	422.30	3.2	
60607	422.30	25.8	
60609	422.30	31.5	

Table 2 Cont: LO_2 Tank Body Point Locations

BODY PT	COORDINATES X_T (in)	θ_T (deg)	LOCATION
60610	422.30	37.2	LO_2 Tank Acreage
60617	422.30	59.8	
60701	432.10	5.0	
60707	432.10	23.7	
60709	432.10	31.5	
60711	432.10	39.4	
60716	432.10	58.0	
60802	437.60	5.9	
60806	437.60	21.5	
60807	437.60	26.5	
60809	437.60	31.5	
60810	437.60	36.5	
60816	437.60	57.1	
71100	453.60	0.0	
71150	453.60	180.0	
71175	467.40	270.0	
71200	467.40	0.0	
71250	467.40	180.0	
71263	467.40	225.0	
71275	467.40	270.0	
71288	467.40	315.0	
60907	474.20	23.7	
60909	474.20	31.5	
60911	474.20	39.3	
60915	474.20	53.5	
61009	512.10	31.5	
61109	512.60	31.5	
71300	513.60	0.0	
71350	513.60	180.0	
71356	513.60	202.5	
71363	513.60	225.0	
71369	513.60	247.5	
71375	513.60	270.0	

Table 2 Cont: LO_2 Tank Body Point Locations

BODY PT	COORDINATES		LOCATION
	X_T (in)	θ_T (deg)	
71381	513.60	292.5	LO_2 Tank Acreage
71388	513.60	315.0	
71394	513.60	337.5	
61111	551.30	37.3	
61114	551.30	49.0	
61209	591.40	31.5	
71400	606.00	0.0	
71450	606.00	180.0	
71456	606.00	202.5	
71463	606.00	225.0	
71469	606.00	247.5	
71475	606.00	270.0	
71481	606.00	292.5	
71488	606.00	315.0	
71494	606.00	337.5	
61309	632.30	31.5	
61311	632.30	36.4	
61313	632.30	46.3	
61409	673.90	31.5	
71500	698.00	0.0	
71550	698.00	180.0	
71556	698.00	202.5	
71563	698.00	225.0	
71569	698.00	247.5	
71575	698.00	270.0	
71581	698.00	292.5	
71588	698.00	315.0	
71594	698.00	337.5	
61509	715.80	31.5	
71600	751.50	0.0	
71650	751.50	180.0	
71675	751.50	270.0	

Table 2 Cont: LO_2 Tank Body Point Locations

BODY PT	COORDINATES		LOCATION
	X_T (in)	θ_T (deg)	
61609	759.20	31.5	LO_2 Tank Acreage
61610	759.20	33.8	
61611	759.20	36.0	
61613	759.20	45.1	
61709	762.20	31.5	
61809	773.70	31.5	
61909	786.20	31.5	
62009	793.10	31.5	
71700	796.50	0.0	
71750	796.50	180.0	
71756	796.50	202.5	
71763	796.50	225.0	
71769	796.50	247.5	
71775	796.50	270.0	
71781	796.50	292.5	
71788	796.50	315.0	
71794	796.50	337.5	
62109	827.10	31.5	
71800	841.50	0.0	
71850	841.50	180.0	
71875	841.50	270.0	

TABLE 3: INTERTANK BODY POINT LOCATIONS

BODY PT	COORDINATES X_T (in)	θ_T (deg)	LOCATION
7300	884.85	0.0	Intertank Acreage
7309	884.85	180.0	
7307	884.85	225.0	
7305	884.85	270.0	
7304	884.85	292.5	
7302	884.85	315.0	
7301	884.85	337.5	
7306	884.86	247.5	
6410	890.00	141.3	
6413	900.00	142.6	
6394	905.00	31.5	
7320	929.14	0.0	
7329	929.14	180.0	
7325	929.14	270.0	
7324	929.14	292.5	
7355	961.22	270.0	
1002	965.22	270.0	
1007	970.22	270.5	
1009	970.22	271.0	
1005	970.22	270.0	
1011	971.22	271.6	
7350	973.43	0.0	
7359	973.43	180.0	
7354	973.43	292.5	
7352	973.43	315.0	
6301	983.46	23.5	
1012	991.07	270.0	
7365	994.40	270.0	
7360	1006.65	0.0	
6368	1006.65	15.0	
6369	1006.65	19.0	
6367	1006.65	29.0	
7369	1006.65	180.0	

Table 3 Cont: Intertank Body Point Locations

BODY PT	COORDINATES		LOCATION
	X_T (in)	θ_T (deg)	
7364	1006.65	292.5	Intertank Acreage
1746	1021.70	13.5	
1738	1021.70	29.3	
7387	1025.80	225.0	
7386	1025.80	247.5	
6331	1026.00	16.5	
7380	1038.03	0.0	
7385	1038.03	270.0	
7381	1038.03	337.5	
7400	1069.40	0.0	
6408	1069.40	15.0	
6409	1069.40	19.0	
6407	1069.40	29.0	
7409	1069.40	180.0	
7406	1069.40	247.5	
7405	1069.40	270.0	
7404	1069.40	292.5	
7401	1069.40	337.5	
6395	1074.40	36.0	
56282	1080.05	32.5	
7420	1102.62	0.0	
6429	1102.62	19.0	
6427	1102.62	29.0	
6424	1102.62	37.7	
7429	1102.62	180.0	
7427	1102.62	225.0	
7426	1102.62	247.5	
7425	1102.62	270.0	
7424	1102.62	292.5	
7422	1102.62	315.0	
7421	1102.62	337.5	
6286	1111.20	23.5	
1100	1111.85	343.0	

Table 3 Conc: Intertank body Point Locations

BODY PT	COORDINATES X_T (in)	θ_T (deg)	LOCATION
1107	1111.85	348.0	Intertank Acreage
1101	1121.08	343.0	
1108	1121.08	348.0	
7430	1123.15	0.0	
7439	1123.15	180.0	
7437	1123.15	225.0	
7436	1123.15	247.5	
7435	1123.15	270.0	
7434	1123.15	292.5	
7432	1123.15	315.0	
7431	1123.15	337.5	

Table 4: LH_2 Tank Body Point Locations

BODY PT	COORDINATES		LOCATION
	X_T (in)	θ_T (deg)	
56283	1124.50	32.5	LH_2 Tank Acreage
6582	1127.56	23.5	
7440	1137.29	0.0	
7449	1137.29	180.0	
7447	1137.29	225.0	
7446	1137.29	247.5	
7445	1137.29	270.0	
7444	1137.29	292.5	
7442	1137.29	315.0	
7441	1137.29	337.5	
1115	1139.53	12.0	
1122	1139.53	17.0	
1105	1139.53	343.0	
1110	1139.53	348.0	
56505	1149.99	32.5	
50108	1151.80	30.9	
50109	1151.80	30.9	
50111	1151.80	30.9	
7450	1167.21	0.0	
7459	1167.21	180.0	
7457	1167.21	225.0	
7455	1167.21	270.0	
7452	1167.21	315.0	
7451	1167.21	337.5	
7470	1201.51	0.0	
7475	1201.51	270.0	
56575	1204.74	32.5	
7479	1209.51	180.0	
7480	1229.96	0.0	
6489	1229.96	19.0	
7489	1229.96	180.0	
7485	1229.96	260.0	
56525	1269.24	32.5	
50308	1270.20	30.9	

Table 4 Cont: LH_2 Tank Body Point Locations

BODY PT	COORDINATES X_T (in)	COORDINATES θ_T (deg)	LOCATION
50309	1270.20	30.9	LH_2 Tank Acreage
50311	1270.20	30.9	
7520	1297.83	0.0	
7529	1297.83	180.0	
7525	1297.83	270.0	
6587	1334.37	23.5	
6588	1358.90	23.5	
7550	1359.15	0.0	
6555	1359.15	40.0	
7559	1359.15	180.0	
7557	1359.15	225.0	
7556	1359.15	247.5	
7555	1359.15	270.0	
7554	1359.15	292.5	
7552	1359.15	315.0	
7551	1359.15	337.5	
6589	1366.38	23.5	
6590	1371.99	23.5	
6593	1375.26	23.5	
6594	1380.41	23.5	
6595	1383.91	23.5	
6596	1387.65	23.5	
50508	1399.40	30.9	
50509	1399.40	30.9	
50511	1399.40	30.9	
6597	1401.00	23.5	
7620	1486.49	0.0	
7629	1486.49	180.0	
7625	1486.49	270.0	
56534	1591.74	32.5	
50808	1593.20	30.9	
50809	1593.20	30.9	
50811	1593.20	30.9	

Table 4 Cont: LH_2 Tank Body Point Locations

BODY PT	COORDINATES		LOCATION
	X_T (in)	θ_T (deg)	
56535	1597.19	32.5	LH_2 Tank Acreage
7690	1615.67	0.0	
6699	1615.67	19.0	
7699	1615.67	180.0	
7697	1615.67	225.0	
7696	1615.67	247.5	
7695	1615.67	270.0	
7694	1615.67	292.5	
7692	1615.67	315.0	
7691	1615.67	337.5	
6603	1618.69	23.5	
6606	1621.96	23.5	
7760	1743.02	0.0	
7769	1743.02	180.0	
7767	1743.02	225.0	
7766	1743.02	247.5	
7764	1743.02	292.5	
7762	1743.02	315.0	
7761	1743.02	337.5	
1401	1822.38	309.4	
6614	1865.39	23.5	
1404	1868.51	309.4	
6617	1868.66	23.5	
7830	1872.20	0.0	
7839	1872.20	180.0	
7837	1872.20	225.0	
7836	1872.20	247.5	
7835	1872.20	270.0	
7834	1872.20	292.5	
7832	1872.20	315.0	
7831	1872.20	337.5	
7850	1898.04	0.0	
7859	1898.04	180.0	
7855	1898.04	270.0	

Table 4 Cont: LH_2 Tank Body Point Locations

BODY PT	COORDINATES X_T (in)	COORDINATES θ_T (deg)	LOCATION
7852	1898.04	315.0	LH_2 Tank Acreage
56565	1914.24	32.5	
1406	1914.65	304.0	
1409	1914.65	315.0	
51308	1916.00	30.9	
51309	1916.00	30.9	
51311	1916.00	30.9	
1414	1936.79	330.2	
6632	1955.30	23.5	
6633	1962.78	23.5	
6634	1968.39	23.5	
6637	1971.66	23.5	
6638	1976.81	23.5	
56575	1978.74	32.5	
6639	1980.31	23.5	
6640	1984.05	23.5	
6909	1999.54	19.0	
51608	2028.00	30.9	
51609	2028.00	30.9	
51611	2028.00	30.9	
1021	2031.65	289.5	
1300	2032.00	355.0	
6647	2033.00	23.5	
6929	2036.45	19.0	
7920	2036.46	0.0	
7929	2036.46	180.0	
7925	2036.46	270.0	
7922	2036.46	315.0	
7921	2036.46	337.5	
1041	2040.75	250.5	
1023	2048.45	289.5	
1043	2048.75	250.5	
1025	2052.65	289.5	
1205	2053.50	312.6	
1303	2053.50	355.0	

Table 4 Conc: LH_2 Tank Body Point Locations

BODY PT	COORDINATES		LOCATION
	X_T (in)	θ_T (deg)	
1046	2053.75	250.0	LH_2 Tank Acreage
7930	2058.00	0.0	
7939	2058.00	180.0	
7937	2058.00	255.0	
1054	2058.00	247.0	
7935	2058.00	270.0	
1032	2058.00	283.9	
1211	2058.00	319.4	
7931	2058.00	337.5	
1307	2058.00	357.1	
1309	2058.00	358.8	
1704	2058.00	340.0	
1047	2063.25	250.5	
1705	2063.60	340.0	
1206	2064.00	312.6	
1305	2064.50	355.0	
1026	2065.45	289.5	
1306	2067.50	355.0	
1207	2072.00	312.6	
1049	2075.25	250.5	
1028	2075.95	289.5	
1050	2083.25	250.5	
1712	2084.40	343.8	
1713	2084.40	344.5	
1715	2084.40	346.3	
1716	2084.40	350.5	

TABLE 5: LIGHT WEIGHT TANK DESIGN TRAJECTORY

a) Freestream Parameters and Dispersions

TIME (SEC.)	ALT. (FT.)	VELOCITY (FT./SEC.)	α (DEG.)	β (DEG.)	ρ_∞ (SLUGS/FT.^{3})	T_∞ (°R)	P_∞ (LBS./FT.^{2})	$-\Delta\alpha$ (DEG.)	$+\Delta\alpha$ (DEG.)	$-\Delta\beta$ (DEG.)	$+\Delta\beta$ (DEG.)
0.0	519.2	20.9	-90.00	19.77	2.3520E-03	517.4	.20887E+04	1.18	1.18	0.0	0.0
10.00	1350.1	183.1	-0.55	0.29	2.2810E-03	517.7	.20268E+04	0.87	0.66	1.18	0.94
20.00	4295.6	429.5	1.63	-5.28	2.0590E-03	515.2	.18211E+04	1.15	0.98	0.61	1.06
30.00	9581.5	709.4	-3.81	-3.16	1.7390E-03	502.0	.14984E+04	0.63	0.56	0.46	0.60
40.00	17023.3	965.3	-3.14	-1.19	1.3790E-03	476.1	.11270E+04	0.34	0.35	0.83	0.84
42.00	18704.5	1008.6	-2.99	-1.21	1.3080E-03	469.7	.10544E+04	0.44	0.40	0.73	0.74
44.00	20430.6	1051.9	-3.09	-1.20	1.2380E-03	462.9	.98370E+03	0.41	0.43	0.71	0.72
46.00	22197.1	1094.9	-3.15	-1.13	1.1700E-03	455.8	.91525E+03	0.57	0.59	0.69	0.70
48.00	23999.9	1138.3	-3.19	-1.19	1.1040E-03	448.3	.84928E+03	0.77	0.75	0.67	0.67
50.00	25837.2	1182.7	-3.57	-1.38	1.0400E-03	440.5	.78591E+03	0.84	0.81	0.65	0.66
52.00	27708.6	1227.7	-3.72	-1.32	9.7710E-04	432.4	.72523E+03	0.66	0.66	0.70	0.71
54.00	29614.8	1275.5	-3.50	-1.42	9.1620E-04	424.3	.66727E+03	0.56	0.57	0.71	0.72
56.00	31557.1	1326.0	-3.31	-1.41	8.5650E-04	416.3	.61208E+03	0.63	0.61	0.71	0.71
58.00	33537.3	1379.2	-3.15	-1.40	7.9870E-04	408.2	.55959E+03	0.65	0.67	0.74	0.75
60.00	35558.0	1434.6	-3.05	-1.33	7.4010E-04	401.1	.50951E+03	0.73	0.76	0.73	0.73
64.00	39754.2	1569.0	-2.51	-1.17	6.2200E-04	391.4	.41789E+03	1.07	1.08	0.65	0.66
68.00	44230.4	1728.7	-1.95	-1.26	5.0940E-04	385.1	.33675E+03	1.28	1.27	0.52	0.54
70.00	46584.6	1814.1	-1.74	-1.38	4.5720E-04	382.5	.30017E+03	1.27	1.73	0.48	0.51
74.00	51533.9	1999.1	-1.20	-1.72	3.6280E-04	377.8	.23523E+03	1.22	1.24	0.40	0.44
78.00	56808.9	2205.7	-0.44	-2.15	2.8040E-04	376.3	.18114E+03	1.29	1.23	0.46	0.52
80.00	59568.8	2313.4	-0.01	-2.43	2.4280E-04	379.2	.15794E+03	1.03	0.95	0.58	0.66
82.00	62406.7	2423.4	-0.12	-2.69	2.1040E-04	381.1	.13769E+03	0.64	0.53	0.77	0.83
84.00	65321.4	2538.7	-0.64	-3.01	1.8130E-04	383.8	.11950E+03	0.34	0.30	0.97	1.05
86.00	68314.6	2656.1	-1.09	-3.40	1.5550E-04	387.0	.10331E+03	0.18	0.20	1.21	1.29
88.00	71388.1	2777.4	-1.31	-3.64	1.3445E-04	390.3	8.9942E+01	0.26	0.15	1.48	1.55
90.00	74540.9	2900.6	-1.27	-3.55	1.1340E-04	393.6	.76574E+02	0.35	0.14	1.55	1.60
92.00	77771.8	3025.4	-1.23	-3.42	9.6630E-05	396.5	.65733E+02	0.41	0.15	1.58	1.64
94.00	81078.4	3153.8	-1.20	-3.31	8.2290E-05	398.9	.56342E+02	0.44	0.24	1.63	2.00
96.00	84457.8	3285.6	-1.14	-3.05	7.0000E-05	401.1	.48211E+02	0.48	0.16	1.82	1.56
98.00	87906.1	3421.7	-1.08	-2.76	5.9400E-05	403.4	.41152E+02	0.51	0.23	1.75	1.78
100.00	91420.8	3566.3	-1.07	-2.97	5.0150E-05	406.5	.34980E+02	0.53	0.23	1.75	1.86
102.00	94998.6	3705.3	-1.04	-2.85	4.2200E-05	410.5	.29733E+02	0.53	0.22	1.67	1.76
104.00	98635.3	3850.0	-1.07	-2.44	3.5985E-05	415.0	2.5581E+01	0.54	0.25	1.18	1.26
106.00	102327.1	3994.7	-1.09	-2.05	2.9770E-05	419.4	.21429E+02	0.54	0.25	1.04	1.11
108.00	106070.6	4143.4	-1.13	-1.90	2.4990E-05	423.7	.18168E+02	0.53	0.24	1.13	1.23

TABLE 5 CONT: LIGHT WEIGHT TANK DESIGN TRAJECTORY

a) Freestream Parameters and Dispersions

TIME (SEC)	ALT. (FT.)	VELOCITY (FT./SEC.)	α (DEG.)	β (DEG.)	ρ_∞ (SLUGS/FT.^{3})	T_∞ (°R)	P_∞ (LBF/FT.^{2})	$-\Delta\alpha$ (DEG.)	$+\Delta\alpha$ (DEG.)	$-\Delta\beta$ (DEG.)	$+\Delta\beta$ (DEG.)
110.00	109862.4	4292.9	-1.15	-1.88	2.0960E-05	428.0	.15397E+02	0.55	0.20	1.42	1.46
112.00	113698.4	4431.9	-1.01	-1.94	1.7580E-05	432.5	.13048E+02	0.58	0.20	3.30	4.32
114.00	117556.6	4534.5	-0.96	-1.99	1.4750E-05	437.4	.11069E+02	0.76	0.45	5.00	6.80
116.00	121404.3	4604.9	-0.81	-2.07	1.2390E-05	442.5	.94135E+01	1.09	0.76	3.52	5.50
118.00	125222.6	4664.6	-0.27	-2.18	1.0450E-05	447.9	.80322E+01	1.31	1.02	2.75	2.79
120.00	129001.1	4714.5	0.17	-2.54	8.8360E-06	453.6	.68790E+01	1.67	1.27	1.95	1.94
122.00	132732.7	4753.7	0.11	-2.90	7.5010E-06	459.4	.59143E+01	1.91	1.42	2.24	2.40
124.00	136411.6	4789.9	-0.38	-3.17	6.3940E-06	465.2	.51053E+01	2.08	1.56	2.94	3.22
126.00	140035.1	4829.4	-0.90	-3.38	5.4750E-06	470.8	.44244E+01	2.10	1.64	3.09	3.40
126.11	140227.3	4831.5	-0.93	-3.39	5.4310E-06	471.1	.43911E+01	2.10	1.67	3.09	3.39
126.12	140227.3	4831.5	-1.03	-3.36	5.4310E-06	471.1	.43911E+01	2.10	1.68	3.09	3.39
128.00	143607.4	4882.6	-1.54	-3.51	4.7100E-06	476.0	.38480E+01	2.12	2.20	3.09	3.15
130.00	147135.1	4932.4	-2.04	-3.59	4.0700E-06	480.6	.33572E+01	2.25	2.02	3.32	3.41
132.00	150619.3	4970.2	-2.44	-7.18	3.5330E-06	484.3	.29373E+01	2.38	1.83	3.55	3.67
134.00	154060.7	5015.0	-2.49	-7.17	3.0840E-06	486.8	.25766E+01	2.51	1.65	3.78	3.93
136.00	157459.1	5063.2	-2.54	-7.15	2.7060E-06	487.8	.22655E+01	2.64	1.46	4.00	4.18
138.00	160814.4	5114.1	-2.58	-7.22	2.3880E-06	486.9	.19960E+01	2.77	1.28	4.23	4.44
140.00	164126.1	5160.7	-2.62	-7.12	2.1010E-06	488.1	.17603E+01	2.90	1.09	4.46	4.70
142.00	167393.8	5209.7	-2.66	-6.98	1.8580E-06	488.3	.15572E+01	3.03	0.91	4.69	4.96
144.00	170617.6	5260.4	-2.70	-6.81	1.6480E-06	487.4	.13791E+01	3.16	0.72	4.92	5.22
146.00	173796.6	5310.6	-2.72	-6.73	1.4670E-06	485.7	.12226E+01	2.84	0.76	4.82	5.09
148.00	176931.1	5354.0	-2.72	-6.57	1.3080E-06	483.1	.10848E+01	2.52	0.79	4.72	4.96
150.00	180020.1	5399.5	-10.91	-10.88	1.1700E-06	480.0	.96353E+00	2.20	0.83	4.62	4.83
152.00	183072.3	5449.6	-11.04	-10.72	1.0470E-06	476.3	.85625E+00	1.88	0.86	4.52	4.70
154.00	186095.6	5494.7	-11.14	-10.51	9.3920E-07	472.1	.76106E+00	1.56	0.90	4.42	4.57
156.00	192056.1	5588.4	-11.32	-10.25	7.5700E-07	462.9	.60145E+00	0.91	0.97	4.22	4.32
158.00	192056.1	5588.4	-11.32	-10.25	7.5700E-07	462.9	.60145E+00	0.91	0.97	4.22	4.32
160.00	194993.4	5622.2	-11.36	-10.15	6.8030E-07	458.0	.53472E+00	0.59	1.00	4.12	4.19
162.00	197902.6	5656.4	-11.41	-9.99	6.1160E-07	452.9	.47539E+00	0.58	0.99	4.08	4.14
164.00	200763.8	5703.8	-11.48	-9.82	5.4990E-07	447.7	.42262E+00	0.57	0.98	4.04	4.10
166.00	203637.1	5751.7	-11.56	-9.65	4.9460E-07	442.5	.37568E+00	0.56	0.97	4.00	4.05
168.00	206462.6	5800.7	-11.62	-9.49	4.4480E-07	437.4	.33393E+00	0.55	0.95	3.96	4.00
170.00	209260.8	5849.8	-11.69	-9.33	4.0000E-07	432.2	.29677E+00	0.54	0.94	3.93	3.96
172.00	212031.6	5899.7	-11.75	-9.18	3.5970E-07	427.2	.26371E+00	0.53	0.93	3.89	3.91
174.00	214775.6	5949.6	-11.80	-9.02	3.2330E-07	422.2	.23429E+00	0.52	0.91	3.85	3.87
176.00	217492.2	5999.9	-11.85	-8.86	2.9050E-07	417.3	.20812E+00	0.51	0.90	3.81	3.82
178.00	220182.7	6051.0	-11.89	-8.71	2.6100E-07	412.6	.18484E+00	0.50	0.89	3.75	3.76
180.00	222846.5	6102.1	-11.92	-8.55	2.3440E-07	408.0	.16413E+00	0.49	0.88	3.69	3.70
182.00	225484.1	6153.6	-11.95	-8.40	2.1040E-07	403.5	.14571E+00	0.49	0.88	3.63	3.64
184.00	228096.1	6205.4	-11.98	-8.24	1.8880E-07	399.1	.12934E+00	0.48	0.87	3.57	3.58
186.00	230681.6	6259.2	-12.00	-8.10	1.6940E-07	394.9	.11478E+00	0.47	0.86	3.51	3.52

TABLE 5 CONT: LIGHT WEIGHT TANK DESIGN TRAJECTORY

a) Freestream Parameters and Dispersions

TIME (SEC.)	ALT. (FT.)	VELOCITY (FT./SEC.)	α (DEG.)	β (DEG.)	ρ_∞ (SLUGS/FT.^{3})	T_∞ (°R)	P_∞ (lbf/FT.^{2})	$-\Delta\alpha$ (DEG.)	$+\Delta\alpha$ (DEG.)	$-\Delta\beta$ (DEG.)	$+\Delta\beta$ (DEG.)
188.00	233242.1	6315.9	-12.02	-7.99	1.5190E-07	390.7	.10184E+00	0.46	0.85	3.45	3.46
190.00	235776.9	6373.2	-12.04	-7.88	1.3610E-07	386.6	.90347E-01	0.46	0.84	3.39	3.40
192.00	238286.6	6431.2	-12.05	-7.78	1.2200E-07	382.6	.80136E-01	0.45	0.83	3.33	3.34
194.00	240771.2	6489.8	-12.06	-7.67	1.0930E-07	378.7	.71069E-01	0.45	0.82	3.27	3.28
196.00	243231.2	6549.0	-12.06	-7.56	9.7970E-08	374.8	.63018E-01	0.44	0.81	3.22	3.22
198.00	245666.6	6608.9	-12.06	-7.46	8.7780E-08	370.8	.55872E-01	0.43	0.81	3.16	3.17
200.00	248078.1	6669.4	-12.05	-7.36	7.8660E-08	366.8	.49531E-01	0.43	0.80	3.10	3.11
202.00	250465.1	6730.6	-12.04	-7.25	7.0500E-08	362.8	.43906E-01	0.42	0.80	3.05	3.05
204.00	252828.1	6792.4	-12.03	-7.15	6.3220E-08	358.7	.38918E-01	0.42	0.79	2.99	3.00
206.00	255167.3	6854.8	-12.01	-7.05	5.6710E-08	354.4	.34495E-01	0.41	0.78	2.94	2.94
208.00	257483.6	6917.9	-11.98	-6.96	5.0890E-08	350.0	.30573E-01	0.40	0.77	2.88	2.89
210.00	259776.2	6981.6	-11.96	-6.86	4.5710E-08	345.3	.27098E-01	0.40	0.77	2.83	2.83
212.00	262046.0	7046.0	-11.92	-6.76	4.1100E-08	340.5	.24018E-01	0.39	0.76	2.77	2.78
214.00	264293.0	7111.1	-11.89	-6.67	3.6990E-08	335.3	.21289E-01	0.39	0.76	2.72	2.73
216.00	266517.6	7176.3	-11.85	-6.57	3.3340E-08	329.8	.18872E-01	0.38	0.75	2.67	2.68
218.00	268719.2	7243.2	-11.80	-6.48	2.9950E-08	325.2	.16720E-01	0.38	0.74	2.62	2.62
220.00	270899.1	7310.3	-11.75	-6.39	2.6500E-08	325.2	.14793E-01	0.38	0.73	2.56	2.57
222.00	273057.1	7378.0	-11.69	-6.29	2.3480E-08	325.2	.13105E-01	0.37	0.73	2.51	2.52
224.00	275193.6	7446.5	-11.63	-6.20	2.0820E-08	325.2	.11624E-01	0.37	0.72	2.46	2.47
226.00	277308.1	7515.6	-11.57	-6.11	1.8490E-08	325.2	.10323E-01	0.36	0.72	2.41	2.42
228.00	279401.4	7585.4	-11.50	-6.02	1.6440E-08	325.2	.91790E-02	0.36	0.71	2.36	2.37
230.00	281473.7	7655.9	-11.43	-5.93	1.4640E-08	325.2	.81715E-02	0.35	0.70	2.31	2.32
232.00	283525.2	7727.1	-11.36	-5.85	1.3050E-08	325.2	.72833E-02	0.35	0.70	2.26	2.27
234.00	285555.9	7799.0	-11.28	-5.76	1.1640E-08	325.2	.64993E-02	0.35	0.69	2.22	2.22
236.00	287566.2	7871.6	-11.19	-5.67	1.0400E-08	325.2	.58065E-02	0.34	0.69	2.17	2.17
238.00	289556.4	7944.9	-11.11	-5.59	9.3040E-09	325.2	.51935E-02	0.34	0.68	2.12	2.12
240.00	291526.6	8018.9	-11.02	-5.50	8.3320E-09	325.2	.46505E-02	0.34	0.67	2.07	2.08
242.00	293477.1	8093.7	-10.92	-5.42	7.4690E-09	325.2	.41690E-02	0.33	0.67	2.02	2.03
244.00	295407.4	8169.2	-10.83	-5.34	6.6990E-09	325.4	.37419E-02	0.33	0.66	1.98	1.99
246.00	297318.7	8245.5	-10.73	-5.26	5.9650E-09	328.6	.33640E-02	0.32	0.66	1.93	1.94
248.00	299210.7	8322.5	-10.62	-5.18	5.3230E-09	331.7	.30305E-02	0.32	0.65	1.89	1.89
250.00	301083.9	8400.2	-10.51	-5.10	4.7610E-09	334.8	.27356E-02	0.32	0.64	1.84	1.85
252.00	302938.2	8478.7	-10.40	-5.02	4.2670E-09	337.8	.24743E-02	0.31	0.64	1.80	1.80
254.00	304774.0	8559.0	-10.29	-4.94	3.8330E-09	340.8	.22422E-02	0.31	0.63	1.75	1.76
256.00	306591.4	8638.0	-10.17	-4.86	3.4490E-09	343.8	.20357E-02	0.31	0.63	1.71	1.71
258.00	308390.6	8718.9	-10.05	-4.78	3.1110E-09	346.8	.18516E-02	0.27	0.61	2.53	2.53
259.93	310113.8	8797.8	-9.93	-4.71	2.8200E-09	349.6	.16921E-02	0.23	0.60	3.32	3.33
259.94	310114.0	8797.8	-16.80	-8.99	2.8200E-09	349.6	.16921E-02	0.23	0.60	3.33	3.33
264.44	314017.6	8908.5	-16.33	-8.88	2.2640E-09	356.1	.13837E-02	0.20	0.56	3.57	3.57
272.00	320198.7	9100.5	-16.05	-8.67	1.6130E-09	366.2	.10136E-02	0.18	0.49	3.58	3.58
280.67	326711.6	9323.2	-15.96	-8.44	1.1390E-09	376.9	.73717E-03	0.18	0.64	3.58	3.58

TABLE 5 CONT: LIGHT WEIGHT TANK DESIGN TRAJECTORY

a) Freestream Parameters and Dispersions

TIME (SEC.)	ALT. (FT.)	VELOCITY (FT./SEC.)	α (DEG.)	β (DEG.)	ρ_∞ (SLUGS/FT.^{3})	T_∞ (°R)	P_∞ (LBF./FT.^{2})	−Δα (DEG.)	+Δα (DEG.)	−Δβ (DEG.)	+Δβ (DEG.)
285.17	329855.2	9448.9	-15.91	-8.31	9.6220E-10	384.1	.63429E-03	0.18	0.72	3.58	3.58
288.00	331749.5	9526.4	-15.70	-8.24	8.6850E-10	389.3	.58030E-03	0.18	0.76	3.58	3.58
304.00	341337.6	9982.0	-15.19	-7.82	5.2790E-10	415.6	.37653E-03	0.20	0.51	3.56	3.56
320.00	349089.6	10468.1	-14.52	-7.40	3.6110E-10	436.8	.27073E-03	0.24	0.52	3.55	3.55
323.83	350686.1	10589.0	-14.34	-7.30	3.3470E-10	441.2	.25346E-03	0.25	0.52	3.55	3.55
336.00	355134.9	10986.2	-13.71	-6.99	2.7200E-10	453.4	.21166E-03	0.28	0.54	3.57	3.57
352.00	359607.5	11538.5	-12.77	-6.60	2.2200E-10	465.7	.17746E-03	0.34	0.57	3.57	3.57
362.48	361750.6	11919.9	-12.11	-6.34	2.0080E-10	473.9	.16337E-03	0.36	0.58	3.62	3.62
368.00	362641.5	12123.8	-11.90	-6.18	1.9220E-10	478.8	.15793E-03	0.38	0.59	3.65	3.65
384.00	364346.1	12740.9	-10.85	-5.80	1.7680E-10	488.2	.14817E-03	0.46	0.64	3.68	3.68
400.00	364871.4	13398.5	-9.69	-5.44	1.7240E-10	491.0	.14532E-03	0.55	0.71	3.71	3.71
416.00	364387.9	14100.5	-8.44	-5.07	1.7650E-10	488.4	.14794E-03	0.67	0.79	3.75	3.75
432.00	363077.0	14850.8	-7.11	-4.72	1.8810E-10	481.2	.15536E-03	0.80	0.89	3.80	3.80
448.00	361132.3	15654.5	-5.70	-4.36	2.0710E-10	470.5	.16729E-03	0.74	0.79	3.86	3.86
464.00	358762.9	16517.5	-4.22	-4.00	2.3060E-10	463.4	.18340E-03	0.62	0.64	3.94	3.94
480.00	356195.2	17446.8	-2.69	-3.63	2.5910E-10	456.3	.20291E-03	0.52	0.51	4.07	4.07
496.00	353676.8	18450.8	-1.12	-3.25	2.9090E-10	449.4	.22442E-03	0.44	0.39	4.22	4.22
512.00	351480.1	19540.0	0.48	-2.86	3.2240E-10	443.4	.24535E-03	0.36	0.28	4.43	4.43
528.00	349904.1	20726.9	2.05	-2.43	3.4730E-10	439.1	.26176E-03	0.32	0.19	4.70	4.70
544.00	349275.6	22027.3	3.68	-1.92	3.5790E-10	437.3	.26865E-03	0.29	0.14	5.12	5.12
560.00	349943.4	23464.2	5.29	-1.30	3.4670E-10	439.2	.26133E-03	0.27	0.09	5.78	5.78
561.25	350060.1	23582.5	5.41	-1.25	3.4480E-10	439.5	.26008E-03	0.28	0.10	5.84	5.84
576.00	352228.7	24992.4	6.68	-0.56	3.1120E-10	445.4	.23797E-03	0.39	0.23	6.61	6.61
581.99	353534.3	25565.9	7.04	-0.72	2.9290E-10	449.0	.22571E-03	0.46	0.28	6.67	6.67
592.00	355886.2	25563.1	7.02	-0.73	2.6280E-10	455.5	.20542E-03	0.46	0.28	6.67	6.67
608.00	359482.4	25558.7	6.99	-0.74	2.2330E-10	465.3	.17832E-03	0.46	0.28	6.67	6.67
611.00	360134.1	25557.9	6.99	-0.74	2.1680E-10	467.1	.17387E-03	0.46	0.28	6.67	6.67

Table 5 Cont: Light Weight Tank Design Trajectory Parameters

b) Dispersed Angle of Attack and Yaw

TIME (Sec)	ALTITUDE (Ft)	VELOCITY (Ft/Sec)	α^+ (Deg)	α^- (Deg)	β^+ (Deg)	β^- (Deg)
0.0	519.3	0.0	0.00	0.00	0.00	0.00
10.0	1350.0	183.0	0.11	-1.42	1.23	-0.58
20.0	4295.7	429.5	2.61	0.48	-4.22	-5.89
30.0	9581.5	709.4	-3.21	-4.44	-2.56	-3.62
40.0	17023.3	965.3	-2.89	-3.48	-0.35	-2.02
50.0	25837.2	1182.7	-2.76	-4.41	-0.76	-2.03
60.0	35558.0	1434.6	-2.29	-3.78	-0.61	-2.07
70.0	46584.6	1814.1	-0.01	-3.01	-1.23	-1.86
74.0	51534.0	1999.1	0.04	-2.42	-1.28	-2.12
78.0	56809.0	2205.7	0.79	-1.73	-1.63	-2.61
82.0	62406.7	2423.4	0.41	-0.76	-1.86	-3.46
86.0	68314.8	2656.1	-0.89	-1.27	-2.11	-4.61
90.0	74541.1	2900.6	-1.13	-1.62	-1.95	-5.10
94.0	81078.6	3153.8	-0.96	-1.64	-1.31	-4.94
98.0	87906.3	3421.7	-0.85	-1.59	-0.98	-4.51
102.0	94998.7	3705.3	-0.82	-1.57	-1.09	-4.52
106.0	102327.3	3994.7	-0.84	-1.63	-0.94	-3.09
110.0	109862.6	4292.8	-0.95	-1.70	-0.42	-3.30
114.0	117556.8	4534.5	-0.51	-1.72	4.81	-6.99
118.0	125222.7	4664.6	0.75	-1.58	0.61	-4.93
122.0	132732.9	4753.7	1.53	-1.80	0.11	-5.15
126.0	140035.2	4829.4	0.74	-3.00	0.02	-6.47
130.0	147135.3	4932.4	-0.02	-4.29	-0.18	-6.91
140.0	164126.2	5160.7	-1.53	-5.52	-2.42	-11.58
150.0	180020.3	5399.5	-10.08	-13.11	-6.05	-15.50
160.0	194993.6	5622.2	-10.36	-11.95	-5.97	-14.27
180.0	222846.8	6102.1	-11.04	-12.41	-4.85	-12.24
200.0	248078.1	6669.4	-11.25	-12.48	-4.26	-10.47
220.0	270899.5	7310.3	-11.02	-12.13	-3.81	-8.94
240.0	291526.9	8018.9	-10.35	-11.36	-3.42	-7.57
260.0	310114.3	8797.8	-16.20	-17.03	-5.66	-12.32
288.0	331749.8	9526.4	-14.94	-15.88	-4.67	-11.83
304.0	341337.6	9982.1	-14.68	-15.39	-4.26	-11.38

Table 5 Conc: Light Weight Tank Design Trajectory Parameters

b) Dispersed Angle of Attack and Yaw

TIME (Sec)	ALTITUDE (Ft)	VELOCITY (Ft/Sec)	α^+ (Deg)	α^- (Deg)	β^+ (Deg)	β^- (Deg)
320.0	349089.8	10468.1	-14.00	-15.39	-4.26	-11.38
336.0	355135.3	10986.2	-13.17	-13.99	-3.42	-10.56
368.0	362641.8	12123.8	-11.31	-12.28	-2.53	-9.83
384.0	364346.5	12740.9	-10.21	-11.31	-2.12	-9.48
400.0	364871.5	13398.5	-8.98	-10.24	-1.73	-9.15
416.0	364388.3	14100.5	-7.65	-9.11	-1.32	-8.82
432.0	363077.3	14850.8	-6.22	-7.91	-0.92	-8.52
464.0	358763.2	16517.5	-3.58	-4.84	-0.06	-7.94
480.0	356195.5	17446.8	-2.18	-3.21	0.44	-7.70
496.0	353677.2	18450.8	-0.73	-1.56	0.97	-7.47
528.0	349904.3	20726.9	2.24	1.70	2.27	-7.13
544.0	349275.7	22027.3	3.82	3.39	3.20	-7.04
560.0	349943.8	23464.2	5.38	5.02	4.48	-7.08
576.0	352229.1	24992.4	6.91	6.29	6.05	-7.17
592.0	355886.6	25563.1	7.30	6.56	5.94	-7.40
611.0	360134.5	25557.9	7.27	6.53	5.93	-7.41

Table 6: Methodology - Nose Spike and Nose Cone Points

- Computer Code - LANMIN

Body Section	Shock Shape	Surface Pressure
30° Cone	30° Cone	30° Cone
10° Cone	30° Cone	10° Cone
40° Cone	39.38° Cone	39.38° Cone

- Boundary Layer Transition Criteria
  - Turbulent $\frac{Re_\theta}{M_1} > 94$
  - Transitional $47 \leq \frac{Re_\theta}{M_1} \leq 94$
  - Laminar $\frac{Re_\theta}{M_1} < 47$
- Laminar Heat Transfer Method - Eckert
- Turbulent Heat Transfer Method - Spaulding Chi
- Rarefied Option Used - Switching Criteria from Boundary Layer to Rarefied to Free Molecular

$A = \frac{M_\infty}{Ze(Re_{\infty_x})^{0.5}}$ Flight Regime Selection Parameter

If $A \leq 0.05$ Boundary Layer

If $0.05 < A < 3.0$ Rarefied

If $A > 3.0$ Free Molecular

M_∞ = Free Stream Mach Number

Re_{∞_x} = Free Stream Reynold's Number Based on Running Length

Ze = Post Normal Shock Compressibility

- Roughness Factor = 1.0
- Mangler Factors (2D to Axisymmetric) - Boundary Layer Only
  - Laminar $N_L = 3$
  - Turbulent $N_T = 2$
- Wall Temperature = 460° R
- Natural Atmosphere - Vandenburg Hot
- Trajectory - LWT Thermal Design Trajectory (1980)

Table 7: Methodology - LO_2 Tank Points

- Computer Code - ETCHECK
- Shock Shape - 39.38° Cone
- Surface Pressure - REMTECH Empirical Curve Fits For ET
- Boundary Layer Heat Transfer Methods
  - Laminar - Eckert
  - Turbulent - Spaulding Chi
- Reynolds Analogy - Colburn
- Roughness Factor - 1.3 for Ogive
  - 1.1 for Ogive Barrel
- Boundary Layer Transition Criteria
  - Turbulent $\frac{Re_\theta}{M_1} > 94$
  - Transitional $47 \leq \frac{Re_\theta}{M_1} \leq 94$
  - Laminar $\frac{Re_\theta}{M_1} < 47$
- Mangler Factors (2D to Axisymmetric) - Boundary Layer Only
  - Laminar $N_L = 3$
  - Turbulent $N_T = 2$
- Wall Temperature = 460° R
- Trajectory - LWT Thermal Design Trajectory (1980)
- Natural Atmosphere - Vandenburg Hot

Table 8: Methodology - Intertank Points

- Computer Code - ETCHECK
- Shock Shape - 39.38° Cone
- Surface Pressure - REMTECH Empirical Curve Fits For ET
- Boundary Layer Heat Transfer Methods
  - Laminar - Eckert
  - Turbulent - Spaulding Chi
- Reynolds Analogy - Colburn
- Roughness Factor - 1.15
- Boundary Layer Transition Criteria
  - Turbulent $\frac{Re_\theta}{M_1} > 94$
  - Transitional $47 \leq \frac{Re_\theta}{M_1} \leq 94$
  - Laminar $\frac{Re_\theta}{M_1} < 47$
- Mangler Factors (2D to Axisymmetric) - Boundary Layer Only
  - Laminar $N_L = 3$
  - Turbulent $N_T = 2$
- Stringer Factors
  - Minor Crossflow - Equation Page 11 Section 4.3.3
  - Major Crossflow - Uses the Table Below:

M_∞	Stringer/Waviness Factor
1.0	1.00
3.0	1.28
4.0	1.37
5.3	1.46

- Flight/Wind Tunnel Scaling Factors Were Used For Some Body Points
- Wall Temperature = 460° R
- Trajectory - LWT Thermal Design Trajectory (1980)
- Natural Atmosphere - Vandenburg Hot

Table 9: Methodology - LH_2 Tank Points

- Computer Code - ETCHECK
- Shock Shape - 39.38 ° Cone
- Surface Pressure - REMTECH Empirical Curve Fits For ET
- Boundary Layer Heat Transfer Methods
  - Laminar - Eckert
  - Turbulent - Spaulding Chi
- Reynolds Analogy - Colburn
- Roughness Factor - 1.1
- Boundary Layer Transition Criteria
  - Turbulent $\frac{Re_\theta}{M_1} > 47$
  - Laminar $\frac{Re_\theta}{M_1} < 47$
- Mangler Factors (2D to Axisymmetric) - Boundary Layer Only
  - Laminar $N_L = 3$
  - Turbulent $N_T = 2$
- Wall Temperature = 460 ° R
- Trajectory - LWT Thermal Design Trajectory (1980)
- Natural Atmosphere - Vandenburg Hot

Table 10: Rarefied Flow Sharp and Blunt Cone Heat Transfer Equations

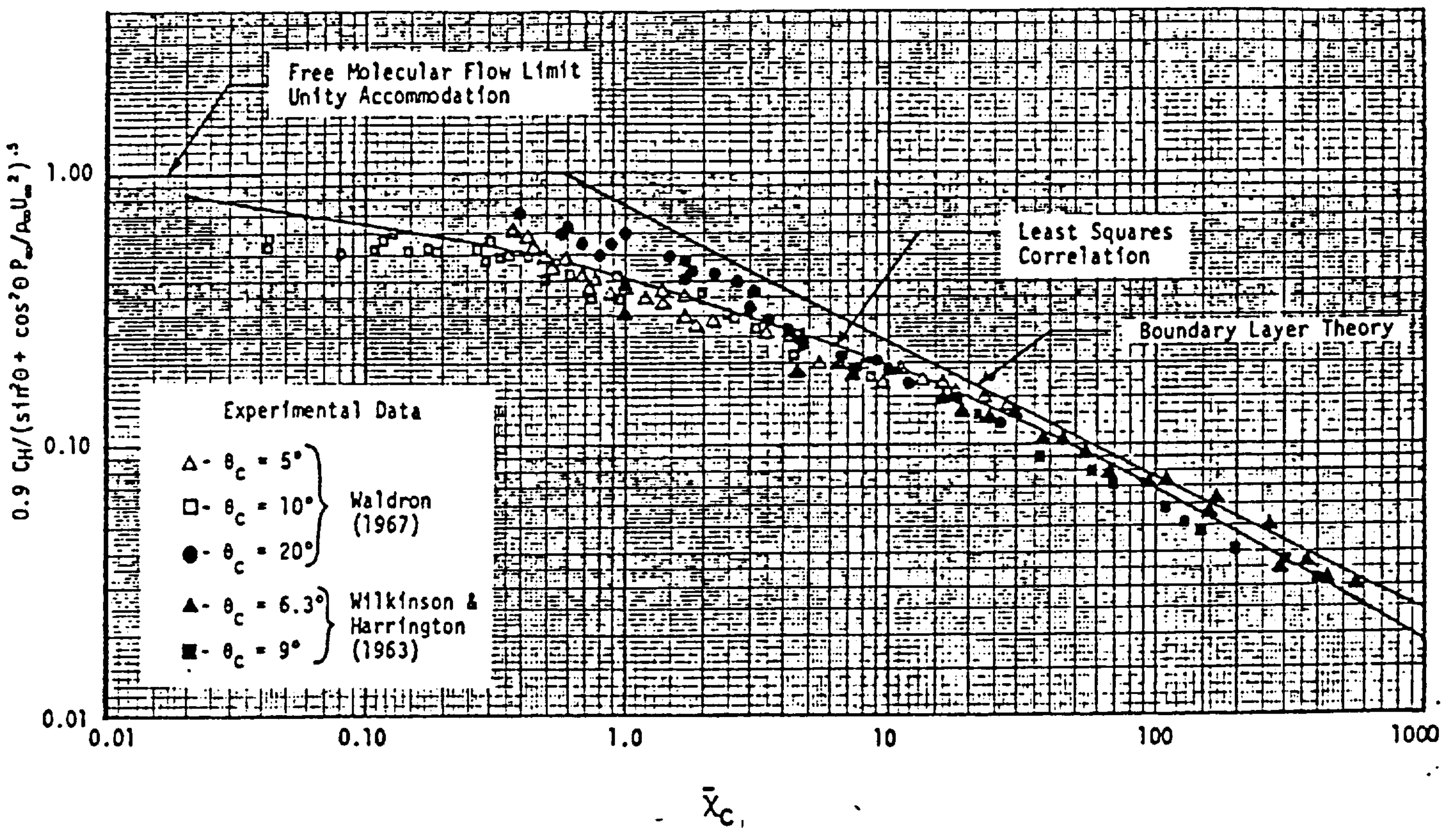
1. $T_R = T_W + (T_\delta + T_W)/2 - T_\delta \cos^2 \theta_C/3$
2. $Re_\infty = \frac{\rho_\infty U_\infty X}{\mu_\infty}$
3. $C^* = \frac{\mu_r T_\delta}{\mu_\delta T_r}$
4. $\eta = \frac{.9C_H}{(\sin^2\theta_C + P_\infty \cos^2\theta_C/\rho_{infty} U_\infty^2)^{.5}}$
5. $\overline{X}_C = \frac{Re_\infty Ze}{M_\infty^2 Y_\infty C * \cos\theta_C}$
6. Correlation Equation

   $\log_{10}(\eta) = \sum 3i = oa_i(\log_{10} \overline{X}_C)^i$

   $$\text{Sharp}\begin{cases} a_0 = -0.344074 \\ a_1 = -0.349130 \\ a_2 = -0.104455 \\ a_3 = +0.022766463 \end{cases} \qquad \text{Blunt}\begin{cases} a_0 = -0.647813 \\ a_1 = -0.365587 \\ a_2 = -0.0143793 \\ a - 3 = +0.003281793 \end{cases}$$

7. Heat Transfer

   $q = \rho_\infty U_\infty C_H (H_O - H_W)$



Sharp Cone Heat Transfer Data

Nomenclature

C_H	Stanton Number
H	Enthalpy
M_∞	Free Stream Mach Number
T	Temperature
U	Velocity
Z	Post Normal Shock Compressibility
ρ	Density
γ	Specific Heat Ratio
μ	Viscosity

Subscripts

∞	Free Stream
W	Wall
δ	Post Normal Shock
o	Total

TABLE 11: TYPICAL EXAMPLE OF H_i/H_u INPUT

BODY PT 7420 T/C 623
XT=1102.6, THETAT= 0.0
@ M(1)=1.0, HI/HU=1. PHASE 1

ALPHA	BETA	HI/HU O/T/S MACH= 3.	HI/HU O/T/S MACH= 4.	HI/HU O/T MACH= 4.	HI/HU O/T MACH=5.3
-5.	-9.	3.25	4.05	4.13	3.92
	-6.	3.14	3.98	3.97	4.00
	-3.	3.05	3.77	3.76	4.08
	0.	2.98	3.50	3.50	4.08
	3.	2.72	3.25	3.26	4.08
	6.	2.55	4.12	4.12	4.57
	9.	2.55	5.12	5.10	6.14
0.	-9.	3.53	3.28	3.28	4.98
	-6.	3.53	3.62	3.60	4.74
	-3.	3.19	3.72	3.72	4.50
	0.	2.84	3.28	3.28	4.75
	3.	3.08	3.76	3.75	4.32
	6.	3.48	3.52	3.53	5.57
	9.	3.64	4.35	4.33	6.06
5.	-9.	3.57	2.65	2.60	4.09
	-6.	3.28	2.72	2.72	4.01
	-3.	2.72	2.90	2.90	3.92
	0.	2.70	2.96	2.97	3.87
	3.	2.96	3.05	3.03	3.81
	6.	2.73	3.03	3.03	4.70
	9.	2.73	3.30	3.30	3.45

PHASE 2

M	HI/HU
4.0	7.7
9.5	7.7
10.0	7.0
11.0	3.0
25.0	3.0

TABLE 12: TYPICAL TIMEWISE THERMAL ENVIRONMENT

Body Point 7432 Environment And Flowfield Parameters, XT=1132.2 in., Theta T=315.0 deg. , Theta S= 0.0 deg.

TIME SEC	ALT KFT	VEL FT/SEC	MACH	ALP DEG	BET DEG	AEFF DEG	RE INF 1/FT	HR BTU/LBM	HCNV LBM/SFT-S	QDOT BTU/SFT-S	QLOAD BTU/SFT	INTRF	FLOW TYPE
10.0	1.350	183.1	0.16	0.00	0.00	0.00	0.9776E+06	0.1339E+03	0.1625E-01	0.3828E+00	0.0000E+00	0.1000E+01	TURB
20.0	4.296	429.5	0.37	0.00	0.00	0.00	0.2153E+07	0.1339E+03	0.3358E-01	0.7902E+00	0.5865E+01	0.1000E+01	TURB
30.0	9.582	709.4	0.63	0.00	0.00	0.00	0.3166E+07	0.1346E+03	0.4513E-01	0.1097E+01	0.1530E+02	0.1000E+01	TURB
40.0	17.023	965.3	0.88	0.00	0.00	0.00	0.3627E+07	0.1354E+03	0.4732E-01	0.1186E+01	0.2672E+02	0.1000E+01	TURB
50.0	25.837	1182.7	1.12	-4.41	-2.03	4.55	0.3578E+07	0.1370E+03	0.4463E-01	0.1189E+01	0.3859E+02	0.1109E+01	TURB
60.0	35.558	1434.6	1.43	-3.78	-2.07	4.14	0.3422E+07	0.1385E+03	0.4582E-01	0.1289E+01	0.5098E+02	0.1387E+01	TURB
70.0	46.585	1814.1	1.93	-3.01	-1.23	3.00	0.3270E+07	0.1478E+03	0.4642E-01	0.1742E+01	0.6614E+02	0.1898E+01	TURB
80.0	59.569	2312.7	2.48	-1.06	-1.74	1.98	0.2163E+07	0.1821E+03	0.3893E-01	0.2795E+01	0.8882E+02	0.2382E+01	TURB
85.0	66.808	2596.8	2.73	-1.16	-2.09	2.30	0.1566E+07	0.2106E+03	0.3146E-01	0.3155E+01	0.1037E+03	0.2524E+01	TURB
90.0	74.541	2900.6	2.99	-1.62	-1.95	2.52	0.1115E+07	0.2444E+03	0.2534E-01	0.3397E+01	0.1201E+03	0.2784E+01	TURB
95.0	82.761	3219.3	3.25	-1.62	-1.19	1.99	0.8324E+06	0.2834E+03	0.1809E-01	0.3132E+01	0.1364E+03	0.2937E+01	TURB
100.0	91.423	3562.8	3.53	-1.57	-1.07	1.87	0.7054E+06	0.3296E+03	0.1197E-01	0.2625E+01	0.1508E+03	0.2897E+01	TURB
105.0	100.476	3921.5	3.81	-1.61	-1.01	1.85	0.6399E+06	0.3823E+03	0.7770E-02	0.2113E+01	0.1626E+03	0.2839E+01	TURB
110.0	109.863	4292.8	4.09	-1.70	-1.86	2.52	0.5601E+06	0.4414E+03	0.5247E-02	0.1737E+01	0.1723E+03	0.2690E+01	TURB
115.0	119.488	4570.9	4.28	-1.65	-1.43	2.17	0.4645E+06	0.4899E+03	0.3848E-02	0.1461E+01	0.1803E+03	0.2745E+01	TURB
120.0	129.004	4710.8	4.34	-1.57	-0.99	1.81	0.3770E+06	0.5173E+03	0.2870E-02	0.1168E+01	0.1868E+03	0.2804E+01	TURB
125.0	138.229	4807.9	4.36	-2.69	-3.08	4.08	0.3073E+06	0.5380E+03	0.2280E-02	0.9751E+00	0.1922E+03	0.2528E+01	TURB
130.0	147.135	4932.4	4.41	-4.29	-6.91	7.92	0.2559E+06	0.5646E+03	0.1289E-02	0.5856E+00	0.1961E+03	0.1473E+01	TURB
135.0	155.768	5045.2	4.46	-4.11	-9.34	9.51	0.2105E+06	0.5887E+03	0.1137E-02	0.5439E+00	0.1989E+03	0.1478E+01	TURB
140.0	164.126	5160.7	4.56	-5.52	-11.58	12.09	0.1605E+06	0.6116E+03	0.1043E-02	0.5229E+00	0.2016E+03	0.1488E+01	TURB
145.0	172.188	5282.1	4.68	-10.41	-14.18	17.39	0.9912E+05	0.6380E+03	0.1030E-02	0.5435E+00	0.2043E+03	0.1502E+01	TURB
150.0	180.020	5399.5	4.87	-13.11	-15.50	20.23	0.5774E+05	0.6596E+03	0.9167E-03	0.5035E+00	0.2069E+03	0.1523E+01	TURB
155.0	187.594	5509.4	5.05	-12.41	-14.87	19.29	0.3519E+05	0.6767E+03	0.7241E-03	0.4101E+00	0.2092E+03	0.1543E+01	TURB
160.0	194.994	5622.2	5.25	-11.95	-14.27	18.54	0.2239E+05	0.6951E+03	0.5755E-03	0.3366E+00	0.2110E+03	0.1565E+01	TURB
165.0	202.203	5734.0	5.45	-12.10	-13.74	18.27	0.1489E+05	0.7144E+03	0.4606E-03	0.2782E+00	0.2126E+03	0.1570E+01	TURB
170.0	209.248	5851.2	5.66	-12.23	-13.22	18.00	0.1037E+05	0.7354E+03	0.3675E-03	0.2297E+00	0.2138E+03	0.1570E+01	TURB
190.0	235.764	6376.5	6.63	-12.50	-11.33	16.85	0.3792E+04	0.8088E+03	0.4889E-04	0.3415E-01	0.2165E+03	0.1570E+01	TURB
210.0	259.763	6981.4	7.83	-12.36	-9.69	15.59	0.1570E+04	0.9376E+03	0.2088E-04	0.1728E-01	0.2170E+03	0.1570E+01	TURB
230.0	281.468	7655.8	8.67	-10.94	-7.49	13.03	0.5104E+03	0.1150E+04	0.1402E-04	0.1457E-01	0.2173E+03	0.1570E+01	TURB
250.0	301.147	8435.3	9.40	-14.87	-10.48	17.93	0.1540E+03	0.1342E+04	0.2287E-04	0.2818E-01	0.2177E+03	0.1578E+01	LAM
270.0	318.551	9048.0	9.68	-16.58	-12.19	20.34	0.5721E+02	0.1541E+04	0.1713E-04	0.2451E-01	0.2183E+03	0.1635E+01	LAM
290.0	333.049	9581.7	9.86	-15.83	-11.77	19.52	0.2602E+02	0.1726E+04	0.1023E-04	0.1653E-01	0.2187E+03	0.1671E+01	LAM
310.0	344.445	10160.6	10.07	-15.17	-11.21	18.65	0.1892E+02	0.1939E+04	0.7382E-05	0.1350E-01	0.2190E+03	0.1700E+01	LAM
330.0	353.047	10788.0	10.40	-14.29	-10.70	17.67	0.1805E+02	0.2182E+04	0.6412E-05	0.1328E-01	0.2192E+03	0.1700E+01	LAM
350.0	359.092	11468.1	10.86	-13.28	-10.24	16.63	0.1780E+02	0.2456E+04	0.6388E-05	0.1498E-01	0.2195E+03	0.1700E+01	LAM
370.0	362.919	12198.7	11.35	-12.16	-9.79	15.52	0.1865E+02	0.2768E+04	0.6806E-05	0.1809E-01	0.2198E+03	0.1700E+01	LAM
390.0	364.662	12982.3	11.97	-10.92	-9.36	14.34	0.2008E+02	0.3122E+04	0.7125E-05	0.2146E-01	0.2202E+03	0.1700E+01	LAM
410.0	364.667	13831.6	12.75	-9.54	-8.94	13.07	0.2139E+02	0.3527E+04	0.7361E-05	0.2515E-01	0.2207E+03	0.1700E+01	LAM
430.0	363.272	14754.0	13.71	-8.07	-8.56	11.76	0.2261E+02	0.3990E+04	0.7891E-05	0.3062E-01	0.2213E+03	0.1700E+01	LAM
450.0	360.785	15756.8	14.84	-6.21	-8.18	10.18	0.2380E+02	0.4529E+04	0.8615E-05	0.3807E-01	0.2219E+03	0.1700E+01	LAM
470.0	357.795	16857.2	16.02	-4.23	-7.85	8.54	0.2671E+02	0.5167E+04	0.9375E-05	0.4740E-01	0.2228E+03	0.1700E+01	LAM
490.0	354.572	18063.8	17.34	-2.18	-7.55	6.88	0.2997E+02	0.5916E+04	0.1027E-04	0.5964E-01	0.2239E+03	0.1700E+01	LAM
510.0	351.614	19393.3	18.78	-0.15	-7.30	5.27	0.3281E+02	0.6803E+04	0.1119E-04	0.7489E-01	0.2252E+03	0.1700E+01	LAM
530.0	349.755	20882.0	20.34	1.91	-7.11	3.68	0.3597E+02	0.7879E+04	0.1180E-04	0.9169E-01	0.2269E+03	0.1700E+01	LAM
550.0	349.337	22555.4	22.00	4.04	-7.05	2.13	0.3904E+02	0.9176E+04	0.1186E-04	0.1076E+00	0.2289E+03	0.1700E+01	LAM
570.0	351.211	24531.5	23.79	5.93	-7.12	0.84	0.4165E+02	0.1085E+05	0.1145E-04	0.1229E+00	0.2312E+03	0.1700E+01	LAM
590.0	355.433	25520.5	24.43	6.54	-7.38	0.59	0.4202E+02	0.1175E+05	0.1068E-04	0.1243E+00	0.2337E+03	0.1700E+01	LAM
610.0	359.914	25576.7	24.16	6.54	-7.42	0.62	0.3917E+02	0.1180E+05	0.9696E-05	0.1134E+00	0.2360E+03	0.1700E+01	LAM

TABLE 13: MAXIMUM DESIGN HEATING RATE AND LOAD SUMMARY

a) Design Environments for the Nose Spike and 40° Cone Acreage

BODY POINT	COORDINATES		LOCATION	MAX HEATING RATES (BTU/ft^2sec)		HEAT LOAD (BTU/ft^2)	
	X_T (in)	θ_T (deg)		RI	REMTECH	RI	REMTECH
7000	—	—	Stag Pt of 1 Ft R. Sphere	5.68	5.75	715.6	920.8
60133	327.66	0.0	30° Conical Nose	14.98	14.98	1840.3	1698.0
60101	328.00	0.0	Tip	11.31	10.93	1593.4	1390.0
60122	328.00	180.0		10.75	10.53	1349.1	1205.0
70300	329.00	0.0		10.21	9.77	1329.2	1090.0
70350	329.00	180.0		9.64	8.99	1147.4	962.3
70375	329.00	270.0		10.87	10.63	1380.5	1158.0
70400	335.00	0.0	10° Nose Cone	4.03	3.77	498.8	439.6
70450	335.00	180.0		3.58	3.40	414.9	370.5
70475	335.00	270.0		4.73	4.26	576.9	503.0
60130	338.00	0.0		3.83	3.57	467.1	411.2
70500	342.24	0.0	40° Cone	15.25	22.07	1434.4	1568.0
70550	342.24	180.0		12.81	21.64	1122.1	1518.0
70575	342.24	270.0		13.50	22.17	1297.6	1603.0
70600	345.50	0.0		18.38	20.48	1593.5	1405.0
70650	345.50	180.0		15.45	20.08	1250.1	1370.0
70675	345.50	270.0		16.28	20.57	1435.6	1429.0
60111	349.00	14.0		22.01	19.41	1574.2	1305.0
70700	354.50	0.0		23.23	18.33	1863.2	1207.0
70750	354.50	180.0		19.52	17.97	1436.5	1184.0
70775	354.50	270.0		20.57	18.41	1643.1	1224.0
60112	357.00	8.0		18.61	17.96	1365.0	1176.0
70800	364.50	0.0		19.02	17.12	1542.7	1108.0
70850	364.50	180.0		15.98	16.78	1217.8	1086.0
70875	364.50	270.0		16.85	17.20	1379.4	1123.0

Note:
1) Maximum heating rates pertain to the aeroheating only. Consequently in plume dominated areas between $96 \leq t \leq 126$ seconds, $\dot{q}_{max}$ is listed for $t \leq 95$ seconds. For plume convection maximum heating rates see Table 14 of this report.
2) Integrated heat loads contain both aeroheating and plume convection.

TABLE 13 CONTINUED
b) DESIGN ENVIRONMENTS FOR THE LO_2 TANK ACREAGE

BODY POINT	COORDINATES		LOCATION	MAX HEATING RATES (BTU/ft^2sec)		HEAT LOAD (BTU/ft^2)	
	X_T (in)	θ_T (deg)		RI	REMTECH	RI	REMTECH
70900	375.10	0.0	LO_2 Tank Acreage	8.97	9.00	817.3	846.2
70950	375.10	180.0		8.89	8.76	825.5	839.5
70956	375.10	202.5		8.83	8.78	816.9	842.1
70963	375.10	225.0		8.96	8.83	845.6	845.4
70969	375.10	247.5		8.99	8.86	849.1	848.6
70975	375.10	270.0		9.00	8.88	846.8	850.3
70981	375.10	292.5		8.87	8.88	808.0	851.3
70988	375.10	315.0		9.01	8.87	829.8	850.1
70994	375.10	337.5		8.93	8.84	816.9	847.8
60400	402.50	357.4		9.23	7.83	750.0	755.0
60405	402.50	16.9		11.56	8.90	875.0	833.8
60407	402.50	24.3		14.34	9.42	1016.1	893.8
60409	402.50	31.5		12.21	10.69	909.2	983.1
60411	402.50	38.7		9.31	9.02	753.0	850.5
60413	402.50	46.1		9.30	7.87	764.6	744.5
60418	402.50	65.6		10.55	7.50	760.3	713.6
60500	409.90	0.1		8.41	8.17	706.2	755.2
60507	409.90	24.9		10.91	8.55	819.7	811.5
60509	409.90	31.5		7.62	7.37	648.6	706.6
60510	409.90	38.1		7.45	7.33	653.8	701.8
60517	409.90	62.9		9.62	7.22	734.2	686.9
71000	421.30	0.0		6.60	7.13	594.5	687.0
71050	421.30	180.0		6.76	6.83	598.0	647.9
71056	421.30	202.5		6.78	7.03	597.7	668.3
71063	421.30	225.0		6.89	7.36	604.4	693.4

Note: 1) Maximum heating rates pertain to the aeroheating only. Consequently in plume dominated areas between $96 \leq t \leq 126$ seconds, $\dot{q}_{max}$ is listed for $t \leq 95$ seconds. For plume convection maximum heating rates see Table 14 of this report.

2) Integrated heat loads contain both aeroheating and plume convection.

TABLE 13 CONTINUED
b) DESIGN ENVIRONMENTS FOR THE LO_2 TANK ACREAGE

BODY POINT	COORDINATES		LOCATION	MAX HEATING RATES (BTU/ft^2sec)		HEAT LOAD (BTU/ft^2)	
	X_T (in)	θ_T (deg)		RI	REMTECH	RI	REMTECH
71069	421.30	247.5	LO_2 Tank Acreage	7.88	7.61	681.2	719.4
71075	421.30	270.0		7.93	7.74	683.4	734.0
71081	421.30	292.5		6.95	7.79	606.7	743.1
71088	421.30	315.0		6.80	7.69	599.9	735.2
71094	421.30	337.5		6.69	7.46	595.0	716.1
60601	422.30	3.2		7.54	7.09	648.8	682.8
60607	422.30	25.8		8.96	8.27	699.0	736.7
60609	422.30	31.5		7.00	8.01	614.7	723.3
60610	422.30	37.2		8.06	6.91	670.3	674.1
60617	422.30	59.8		8.19	6.80	665.2	646.9
60701	432.10	5.0		7.35	6.77	628.5	649.3
60707	432.10	23.7		12.27	11.98	940.0	981.9
60709	432.10	31.5		12.76	10.64	940.1	878.9
60711	432.10	39.4		10.78	10.05	821.6	822.9
60716	432.10	58.0		8.00	6.48	626.2	617.4
60802	437.60	5.9		7.22	8.06	615.4	718.5
60806	437.60	21.5		9.99	10.06	747.7	859.1
60807	437.60	26.5		12.32	12.22	937.5	995.1
60809	437.60	31.5		12.19	12.22	931.1	992.8
60810	437.60	36.5		9.95	9.04	762.0	782.0
60816	437.60	57.1		8.86	8.81	706.9	742.9
71100	453.60	0.0		5.95	6.17	532.9	599.1
71150	453.60	180.0		6.30	5.85	539.8	557.4
71175	467.40	270.0		6.13	6.80	557.2	645.6
71200	467.40	0.0		5.69	5.80	486.5	566.6

Note: 1) Maximum heating rates pertain to the aeroheating only. Consequently in plume dominated areas between $96 \leq t \leq 126$ seconds, $\dot{q}_{max}$ is listed for $t \leq 95$ seconds. For plume convection maximum heating rates see Table 14 of this report.

2) Integrated heat loads contain both aeroheating and plume convection.

TABLE 13 CONTINUED
b) DESIGN ENVIRONMENTS FOR THE LO_2 TANK ACREAGE

BODY POINT	COORDINATES		LOCATION	MAX HEATING RATES (BTU/ft^2sec)		HEAT LOAD (BTU/ft^2)	
	X_T (in)	θ_T (deg)		RI	REMTECH	RI	REMTECH
71250	467.40	180.0	LO_2 Tank Acreage	6.00	5.48	521.8	524.3
71263	467.40	225.0		5.63	6.03	512.3	570.4
71275	467.40	270.0		5.91	6.44	514.4	612.6
71288	467.40	315.0		5.89	6.38	509.0	615.8
60907	474.20	23.7		8.76	7.90	617.5	688.1
60909	474.20	31.5		10.59	10.15	755.9	839.1
60911	474.20	39.3		9.08	8.92	661.1	729.2
60915	474.20	53.5		6.23	8.77	511.3	705.1
61009	512.10	31.5		8.86	7.43	641.5	659.4
61109	512.60	31.5		6.68	7.40	493.5	657.8
71300	513.60	0.0		4.97	4.70	410.4	470.5
71350	513.60	180.0		4.49	4.39	399.3	428.1
71356	513.60	202.5		4.02	4.58	366.8	447.6
71363	513.60	225.0		4.03	4.92	362.0	472.0
71369	513.60	247.5		4.13	5.18	358.2	497.9
71375	513.60	270.0		4.95	5.33	440.7	513.0
71381	513.60	292.5		4.24	5.38	361.9	523.7
71388	513.60	315.0		4.27	5.28	396.6	517.6
71394	513.60	337.5		4.35	5.04	376.9	499.4
61111	551.30	37.3		7.39	4.94	518.8	461.3
61114	551.30	49.0		3.75	3.82	320.9	378.9
61209	591.40	31.5		5.27	3.22	409.7	338.5
71400	606.00	0.0		3.22	2.90	280.8	316.1
71450	606.00	180.0		3.38	2.65	265.7	279.9
71456	606.00	202.5		2.86	2.80	252.0	295.2

Note: 1) Maximum heating rates pertain to the aeroheating only. Consequently in plume dominated areas between $96 \leq t \leq 126$ seconds, $\dot{q}_{max}$ is listed for $t \leq 95$ seconds. For plume convection maximum heating rates see Table 14 of this report.

2) Integrated heat loads contain both aeroheating and plume convection.

TABLE 13 CONTINUED

b) DESIGN ENVIRONMENTS FOR THE LO_2 TANK ACREAGE

BODY POINT	COORDINATES		LOCATION	MAX HEATING RATES (BTU/ft^2sec)		HEAT LOAD (BTU/ft^2)	
	X_T (in)	θ_T (deg)		RI	REMTECH	RI	REMTECH
71463	606.00	225.0	LO_2 Tank Acreage	2.83	3.08	246.6	313.9
71469	606.00	247.5		2.89	3.31	241.9	334.4
71475	606.00	270.0		3.71	3.44	311.8	346.8
71481	606.00	292.5		3.01	3.47	248.7	356.5
71488	606.00	315.0		3.05	3.38	258.2	352.8
71494	606.00	337.5		3.15	3.18	266.6	338.9
61309	632.30	31.5		4.34	3.13	332.4	326.2
61311	632.30	36.4		4.40	2.45	338.3	264.9
61313	632.30	46.3		2.83	3.93	236.3	387.8
61409	673.90	31.5		2.95	3.08	239.7	306.0
71500	698.00	0.0		2.16	1.97	208.7	215.5
71550	698.00	180.0		2.40	1.59	180.4	186.9
71556	698.00	202.5		1.91	1.70	170.6	197.7
71563	698.00	225.0		1.89	1.91	167.8	210.4
71569	698.00	247.5		1.89	2.07	165.1	225.0
71575	698.00	270.0		2.47	2.16	210.8	234.5
71581	698.00	292.5		1.97	2.19	168.0	242.6
71588	698.00	315.0		2.03	2.12	175.3	241.0
71594	698.00	337.5		2.10	2.03	183.0	231.6
61509	715.80	31.5		2.51	2.88	215.6	301.6
71600	751.50	0.0		1.76	1.74	160.0	182.6
71650	751.50	180.0		1.66	1.55	148.5	164.2
71675	751.50	270.0		1.97	1.79	172.6	198.3
61609	759.20	31.5		2.10	2.28	186.1	241.8
61610	759.20	33.8		3.52	2.28	263.7	235.1

Note: 1) Maximum heating rates pertain to the aeroheating only. Consequently in plume dominated areas between $96 \leq t \leq 126$ seconds, $\dot{q}_{max}$ is listed for $t \leq 95$ seconds. For plume convection maximum heating rates see Table 14 of this report.

2) Integrated heat loads contain both aeroheating and plume convection.

TABLE 13 CONTINUED
b) DESIGN ENVIRONMENTS FOR THE LO_2 TANK ACREAGE

BODY POINT	COORDINATES		LOCATION	MAX HEATING RATE (BTU/ft^2sec)		HEAT LOAD (BTU/ft^2)	
	X_T (in)	θ_T (deg)		RI	REMTECH	RI	REMTECH
61611	759.20	36.0	LO_2 Tank Acreage	2.02	1.88	181.4	212.8
61613	759.20	45.1		1.65	1.76	147.8	202.2
61709	762.20	31.5		2.03	1.55	150.6	187.2
61809	773.70	31.5		2.25	2.59	169.6	260.1
61909	786.20	31.5		2.36	2.14	191.7	225.1
62009	793.10	31.5		2.88	2.43	216.5	258.9
71700	796.50	0.0		2.10	1.45	160.7	154.0
71750	796.50	180.0		2.21	1.29	164.1	138.5
71756	796.50	202.5		2.21	1.29	162.8	145.3
71763	796.50	225.0		2.21	1.44	161.6	162.2
71769	796.50	247.5		2.21	1.44	160.2	162.2
71775	796.50	270.0		2.58	1.50	192.4	167.5
71781	796.50	292.5		1.92	1.51	139.3	171.6
71788	796.50	315.0		1.92	1.47	144.7	169.8
71794	796.50	337.5		2.05	1.47	153.3	163.8
62109	827.10	31.5		2.86	2.43	215.6	259.1
71800	841.50	0.0		2.15	1.43	168.7	151.1
71850	841.50	180.0		2.18	1.27	161.5	135.7
71875	841.50	270.0		2.56	1.48	191.7	164.1

Note: 1) Maximum heating rates pertain to the aeroheating only. Consequently in plume dominated areas between $96 \leq t \leq 126$ seconds, $\dot{q}_{max}$ is listed for $t \leq 95$ seconds. For plume convection maximum heating rates see Table 14 of this report.

2) Integrated heat loads contain both aeroheating and plume convection.

TABLE 13 CONTINUED

c) DESIGN ENVIRONMENTS FOR THE INTERTANK ACREAGE

BODY PT	COORDINATES		LOCATION	MAX HEATING RATE (Btu/ft^2-sec)			HEAT LOAD (Btu/ft^2)		
	X_T (in)	θ_T (deg)		RI	REMTECH		RI	REMTECH	
				w/o	w/o	w/	w/o	w/o	w/
7300	884.85	0.0	Intertank Acreage	1.86	1.45	1.53	137.1	153.6	167.9
7309	884.85	180.0		1.95	1.31	1.44	130.7	140.9	153.8
7307	884.85	225.0		1.58	1.46	1.69	107.8	156.1	170.9
7305	884.85	270.0		9.45	5.92	7.88	465.3	374.9	467.7
7304	884.85	292.5		2.00	2.54	3.25	142.9	205.9	250.2
7302	884.85	315.0		2.00	2.47	2.92	147.6	207.1	234.6
7301	884.85	337.5		1.81	1.47	1.71	136.6	161.5	180.7
7306	884.86	247.5		1.61	1.98	2.53	113.9	185.3	219.4
6410	890.00	141.3		2.51	1.63	1.98	201.6	175.5	204.6
6413	900.00	142.6		2.19	1.63	1.97	175.2	175.5	192.4
6394	905.00	31.5		1.33	1.38	1.43	119.9	154.6	167.2
7320	929.14	0.0		1.69	1.44	1.52	131.1	151.5	166.3
7329	929.14	180.0		2.08	1.30	1.39	124.4	142.5	156.7
7325	929.14	270.0		9.89	7.10	9.20	530.2	424.9	532.0
7324	929.14	292.5		4.54	4.74	6.07	242.0	309.7	381.1
7355	961.22	270.0		16.54	16.18	21.80	809.9	895.0	1134.5
1002	965.22	270.0		20.32	16.18	21.80	953.6	895.0	1134.5
1007	970.22	270.5		20.01	16.19	21.81	887.4	895.4	1135.2
1009	970.22	271.0		19.72	16.19	21.82	876.9	895.9	1135.8
1005	970.22	270.0		20.29	16.18	21.80	889.4	895.0	1134.5
1011	971.22	271.6		19.36	16.20	21.83	856.5	896.5	1136.5
7350	973.43	0.0		1.72	1.42	1.58	133.3	148.7	165.1

Note: 1) Maximum heating rates pertain to the aeroheating only. Consequently in plume dominated areas between $96 \leq t \leq 126$ seconds, $\dot{q}_{max}$ is listed for $t \leq 95$ seconds. For plume convection maximum heating rates see Table 14 of this report.

2) Integrated heat loads contain both aeroheating and plume convection.

TABLE 13 CONTINUED
c) DESIGN ENVIRONMENTS FOR THE INTERTANK ACREAGE

BODY PT	COORDINATES		LOCATION	MAX HEATING RATE (Btu/ft^2-sec)			HEAT LOAD (Btu/ft^2)		
	X_T (in)	θ_T (deg)		RI w/o	REMTECH w/o	REMTECH w/	RI w/o	REMTECH w/o	REMTECH w/
7359	973.43	180.0	Intertank Acreage	2.06	1.28	1.40	123.4	136.9	149.1
7354	973.43	292.5		5.90	4.42	5.88	321.7	312.9	386.4
7352	973.43	315.0		5.24	3.15	4.11	316.1	252.7	307.8
6301	983.46	23.5		5.24	3.64	4.75	316.1	364.4	428.6
1012	991.07	270.0		11.81	6.71	9.09	512.2	413.3	519.0
7365	994.40	270.0		11.76	6.71	9.09	510.3	413.3	519.0
7360	1006.65	0.0		1.89	1.41	1.57	139.8	147.4	163.8
6368	1006.65	15.0		2.32	1.96	2.56	155.4	195.1	233.5
6369	1006.65	19.0		3.41	1.95	2.54	193.0	199.5	237.4
6367	1006.65	29.0		2.83	1.86	2.43	170.0	181.1	214.6
7369	1006.65	180.0		2.05	1.27	2.54	122.0	135.9	237.4
7364	1006.65	292.5		2.61	3.19	4.17	170.9	252.0	307.0
1746	1021.70	13.5		3.22	1.84	2.41	193.2	191.3	225.8
1738	1021.70	29.3		2.78	1.97	2.61	173.4	191.1	228.3
7387	1025.80	225.0		2.62	2.20	2.84	169.0	198.1	237.3
7386	1025.80	247.5		2.10	2.00	2.66	156.6	191.4	229.1
6331	1026.00	16.5		3.89	1.95	2.55	253.6	203.2	241.2
7380	1038.03	0.0		2.39	1.67	1.93	158.7	170.9	189.2
7385	1038.03	270.0		1.31	1.51	1.99	123.4	167.2	197.9
7381	1038.03	337.5		2.63	1.94	2.51	175.2	186.5	222.1
7400	1069.40	0.0		2.85	2.04	2.61	189.3	186.4	222.9
6408	1069.40	15.0		3.97	2.16	2.82	251.0	211.5	252.7

Note: 1) Maximum heating rates pertain to the aeroheating only. Consequently in plume dominated areas between 96 $\leq$ t $\leq$ 126 seconds, $\dot{q}_{max}$ is listed for t $\leq$ 95 seconds. For plume convection maximum heating rates see Table 14 of this report.

2) Integrated heat loads contain both aeroheating and plume convection.

TABLE 13 CONTINUED
c) DESIGN ENVIRONMENTS FOR THE INTERTANK ACREAGE

BODY PT	COORDINATES		LOCATION	MAX HEATING RATE (Btu/ft^2-sec)			HEAT LOAD (Btu/ft^2)		
	X_T (in)	θ_T (deg)		RI w/o	REMTECH w/o	REMTECH w/	RI w/o	REMTECH w/o	REMTECH w/
6409	1069.40	19.0	Intertank Acreage	3.89	2.15	2.80	258.9	210.1	250.9
6407	1069.40	29.0		3.39	2.19	2.80	208.0	192.0	229.2
7409	1069.40	180.0		2.10	1.37	1.72	124.2	141.9	164.9
7406	1069.40	247.5		1.49	1.47	1.88	128.3	159.9	188.2
7405	1069.40	270.0		1.31	1.50	1.92	123.6	159.4	187.5
7404	1069.40	292.5		1.82	1.70	2.19	147.8	177.3	210.4
7401	1069.40	337.5		2.94	2.39	2.84	200.4	205.3	233.8
6395	1074.40	36.0		4.42	2.60	3.39	248.7	210.1	252.7
56282	1080.05	32.5		5.01	2.17	2.77	274.0	189.2	225.9
7420	1102.62	0.0		6.78	4.14	4.72	417.4	311.1	337.4
6429	1102.62	19.0		4.72	3.45	4.51	321.8	262.2	322.3
6427	1102.62	29.0		2.09	2.69	3.44	197.7	204.7	245.5
6424	1102.62	37.7		4.72	2.02	2.58	266.8	181.3	216.2
7429	1102.62	180.0		2.25	1.26	1.68	129.9	142.4	166.6
7427	1102.62	225.0		2.48	2.19	2.81	162.7	195.1	233.9
7426	1102.62	247.5		1.52	1.46	1.87	129.3	158.8	187.0
7425	1102.62	270.0		1.30	1.49	1.91	123.7	158.3	186.3
7424	1102.62	292.5		1.64	1.70	2.19	137.5	176.2	209.1
7422	1102.62	315.0		4.42	2.79	3.57	231.8	213.0	255.9
7421	1102.62	337.5		3.77	2.91	3.75	245.2	236.4	288.1
6286	1111.20	23.5		5.09	3.13	4.08	313.1	274.6	337.8
1100	1111.85	343.0		4.64	3.98	5.31	321.6	333.3	411.6
1107	1111.85	348.0		3.76	3.51	4.66	286.9	308.9	379.9

Note: 1) Maximum heating rates pertain to the aeroheating only. Consequently in plume dominated areas between $96 \leq t \leq 126$ seconds, $\dot{q}_{max}$ is listed for $t \leq 95$ seconds. For plume convection maximum heating rates see Table 14 of this report.

2) Integrated heat loads contain both aeroheating and plume convection.

TABLE 13 CONTINUED
c) DESIGN ENVIRONMENTS FOR THE INTERTANK ACREAGE

BODY PT	COORDINATES		LOCATION	MAX HEATING RATE (Btu/ft^2-sec)			HEAT LOAD (Btu/ft^2)		
	X_T (in)	θ_T (deg)		RI	REMTECH		RI	REMTECH	
				w/o	w/o	w/	w/o	w/o	w/
1101	1121.08	343.0		7.08	4.36	5.57	410.8	335.8	413.4
1108	1121.08	348.0		5.55	4.28	5.59	369.1	328.3	409.2
7430	1123.15	0.0		8.36	5.59	7.29	447.2	394.9	497.7
7439	1123.15	180.0		2.24	1.26	1.67	129.2	142.	165.3
7437	1123.15	225.0		2.22	2.18	2.80	156.9	194.5	233.1
7436	1123.15	247.5		1.50	1.46	1.87	129.1	158.1	186.3
7435	1123.15	270.0		1.30	1.49	1.91	124.1	157.6	185.6
7434	1123.15	292.5		1.55	1.70	2.17	134.5	174.7	207.2
7432	1123.15	315.0		6.25	3.40	4.25	296.6	236.0	314.0
7431	1123.15	337.5		4.35	3.19	4.25	260.1	255.5	314.0
56283	1124.50	32.5		4.89	4.23	–	276.1	273.	–

Note: 1) Maximum heating rates pertain to the aeroheating only. Consequently in plume dominated areas between $96 \leq t \leq 126$ seconds, $\dot{q}_{max}$ is listed for $t \leq 95$ seconds. For plume convection maximum heating rates see Table 14 of this report.

2) Integrated heat loads contain both aeroheating and plume convection.

TABLE 13
d) DESIGN ENVIRONMENTS FOR THE LH_2 TANK ACREAGE

BODY POINT	COORDINATES		LOCATION	MAX HEATING RATE (BTU/ft^2sec)		HEAT LOAD (BTU/ft^2)	
	X_T (in)	θ_T (deg)		RI	REMTECH	RI	REMTECH
6582	1127.56	23.5	LH_2 Tank Acreage	5.83	2.98	376.8	260.1
7440	1137.29	0.0		6.47	6.29	406.4	478.9
7449	1137.29	180.0		1.10	1.34	101.9	137.5
7447	1137.29	225.0		1.23	1.36	108.8	144.4
7446	1137.29	247.5		1.19	1.38	107.1	149.8
7445	1137.29	270.0		1.07	1.43	102.5	151.5
7444	1137.29	292.5		1.14	1.44	104.5	163.2
7442	1137.29	315.0		2.41	2.59	176.2	205.6
7441	1137.29	337.5		3.33	4.19	240.5	366.1
1115	1139.53	12.0		6.72	5.83	418.6	408.1
1122	1139.53	17.0		6.32	5.74	354.7	403.3
1105	1139.53	343.0		5.30	4.18	371.1	361.1
1110	1139.53	348.0		4.78	4.47	337.1	384.8
56505	1149.99	32.5		8.45	—	399.0	—
50108	1151.80	30.9		2.93	2.80	215.6	250.2
50109	1151.80	30.9		3.04	3.04	223.9	267.5
50111	1151.80	30.9		2.05	2.07	153.4	198.0
7450	1167.21	0.0		4.26	3.86	312.9	367.7
7459	1167.21	180.0		1.72	1.35	112.2	126.3
7457	1167.21	225.0		1.74	1.39	128.3	131.6
7455	1167.21	270.0		1.06	1.38	98.0	137.5
7452	1167.21	315.0		2.16	2.58	163.7	202.5
7451	1167.21	337.5		2.89	2.92	232.2	243.1
7470	1201.51	0.0		2.85	2.68	208.7	213.0
7475	1201.51	270.0		1.66	1.38	124.0	149.6

Note: 1) Maximum heating rates pertain to the aeroheating only. Consequently in plume dominated areas between $96 \leq t \leq 126$ seconds, $\dot{q}_{max}$ is listed for $t \leq 95$ seconds. For plume convection maximum heating rates see Table 14 of this report.

2) Integrated heat loads contain both aeroheating and plume convection.

TABLE 13 CONTINUED
d) DESIGN ENVIRONMENTS FOR THE LH_2 TANK ACREAGE

BODY POINT	COORDINATES		LOCATION	MAX HEATING RATE (BTU/ft^2sec)		HEAT LOAD (BTU/ft^2)	
	X_T (in)	θ_T (deg)		RI	REMTECH	RI	REMTECH
56515	1204.74	32.5	LH_2 Tank Acreage	11.63	—	573.8	—
7479	1209.51	180.0		1.84	1.37	111.6	126.5
7480	1229.96	0.0		3.65	3.27	219.2	218.4
6489	1229.96	19.0		4.85	3.78	271.7	293.9
7489	1229.96	180.0		1.88	1.40	112.9	127.8
7485	1229.96	260.0		1.66	1.36	123.4	134.3
56525	1269.24	32.5		10.43	—	554.3	—
50308	1270.20	30.9		5.19	5.06	342.0	381.6
50309	1270.20	30.9		5.50	5.49	361.4	407.1
50311	1270.20	30.9		4.15	3.74	277.4	291.4
7520	1297.83	0.0		3.53	2.28	204.7	197.9
7529	1297.83	180.0		1.91	1.44	112.4	126.9
7525	1297.83	270.0		1.64	1.39	121.5	135.2
6587	1334.37	23.5		1.23	1.88	149.4	173.1
6588	1358.90	23.5		1.59	1.88	172.2	172.3
7550	1359.15	0.0		2.02	1.89	155.4	176.4
6555	1359.15	40.0		1.65	1.15	118.9	130.6
7559	1359.15	180.0		1.38	1.51	105.8	127.0
7557	1359.15	225.0		1.14	1.51	95.3	131.9
7556	1359.15	247.5		1.14	1.35	95.2	130.0
7555	1359.15	270.0		1.63	1.40	120.4	135.7
7554	1359.15	292.5		1.23	1.39	100.4	135.3
7552	1359.15	315.0		1.76	2.54	134.4	195.7
7551	1359.15	337.5		1.31	1.47	127.4	170.5
6589	1366.38	23.5		2.24	2.14	211.0	181.3

Note: 1) Maximum heating rates pertain to the aeroheating only. Consequently in plume dominated areas between $96 \leq t \leq 126$ seconds, $\dot{q}_{max}$ is listed for $t \leq 95$ seconds. For plume convection maximum heating rates see Table 14 of this report.

2) Integrated heat loads contain both aeroheating and plume convection.

TABLE 13 CONTINUED

d) DESIGN ENVIRONMENTS FOR THE LH_2 TANK ACREAGE

BODY POINT	COORDINATES		LOCATION	MAX HEATING RATE (BTU/ft^2sec)		HEAT LOAD (BTU/ft^2)	
	X_T (in)	θ_T (deg)		RI	REMTECH	RI	REMTECH
6590	1371.99	23.5	LH_2 Tank Acreage	2.64	2.21	241.7	184.4
6593	1375.26	23.5		3.18	2.25	270.1	186.3
6594	1380.41	23.5		1.09	1.27	139.2	119.9
6595	1383.91	23.5		1.19	1.26	140.7	119.9
6596	1387.65	23.5		1.19	1.26	137.6	119.8
50508	1399.40	30.9		4.21	4.15	303.5	348.6
50509	1399.40	30.9		4.50	4.52	323.2	376.6
50511	1399.40	30.9		2.94	3.07	218.7	265.3
6597	1401.00	23.5		0.94	1.26	118.8	119.6
7620	1486.49	0.0		2.67	1.84	186.6	170.8
7629	1486.49	180.0		2.00	1.55	112.5	127.4
7625	1486.49	270.0		2.47	1.47	147.0	136.9
56534	1591.74	32.5		6.11	—	401.2	—
50808	1593.20	30.9		1.77	2.00	178.5	181.1
50809	1593.20	30.9		2.15	2.17	199.0	194.9
50811	1593.20	30.9		0.93	1.48	105.8	139.6
56535	1597.19	32.5		4.21	—	210.7	—
7690	1615.67	0.0		2.04	1.46	154.3	144.0
6699	1615.67	19.0		3.32	2.34	195.7	212.5
7699	1615.67	180.0		1.84	1.56	119.9	129.4
7697	1615.67	225.0		1.20	1.46	97.6	128.2
7696	1615.67	247.5		1.14	1.31	96.7	123.7
7695	1615.67	270.0		2.04	1.65	137.3	141.0
7694	1615.67	292.5		1.50	2.78	117.1	208.6
7692	1615.67	315.0		1.44	1.69	122.6	150.9

Note: 1) Maximum heating rates pertain to the aeroheating only. Consequently in plume dominated areas between $96 \leq t \leq 126$ seconds, $\dot{q}_{max}$ is listed for $t \leq 95$ seconds. For plume convection maximum heating rates see Table 14 of this report.

2) Integrated heat loads contain both aeroheating and plume convection.

TABLE 13 CONTINUED

d) DESIGN ENVIRONMENTS FOR THE LH_2 TANK ACREAGE

BODY POINT	COORDINATES		LOCATION	MAX HEATING RATE (BTU/ft^2sec)		HEAT LOAD (BTU/ft^2)	
	X_T (in)	θ_T (deg)		RI	REMTECH	RI	REMTECH
7691	1615.67	337.5	LH_2 Tank Acreage	1.70	1.42	126.4	151.2
6603	1618.69	23.5		2.60	2.34	213.7	210.4
6606	1621.96	23.5		3.06	2.34	239.5	210.4
7760	1743.02	0.0		1.34	1.30	126.5	136.3
7769	1743.02	180.0		1.73	1.56	113.6	127.8
7767	1743.02	225.0		1.61	1.39	103.4	123.3
7766	1743.02	247.5		1.22	1.32	98.6	122.6
7764	1743.02	292.5		1.87	2.22	125.6	181.0
7762	1743.02	315.0		1.43	1.51	110.5	146.7
7761	1743.02	337.5		1.15	1.30	106.6	145.4
1401	1822.38	309.4		2.63	1.44	214.9	138.9
6614	1865.39	23.5		2.47	2.36	147.9	164.3
1404	1868.51	309.4		4.73	4.61	386.0	251.8
6617	1868.66	23.5		3.39	3.14	197.3	194.2
7830	1872.20	0.0		1.99	2.42	214.3	245.2
7839	1872.20	180.0		1.34	1.38	156.4	175.5
7837	1872.20	225.0		1.38	1.30	159.2	177.3
7836	1872.20	247.5		1.13	1.32	180.9	202.5
7835	1872.20	270.0		3.15	1.46	217.6	232.3
7834	1872.20	292.5		4.24	1.94	203.9	228.7
7832	1872.20	315.0		1.75	1.85	201.2	237.0
7831	1872.20	337.5		1.55	1.27	196.7	214.6
7850	1898.04	0.0		2.77	1.70	235.8	244.8
7859	1898.04	180.0		1.53	1.23	155.9	171.7
7855	1898.04	270.0		1.98	1.88	182.5	197.2

Note: 1) Maximum heating rates pertain to the aeroheating only. Consequently in plume dominated areas between $96 \leq t \leq 126$ seconds, $\dot{q}_{max}$ is listed for $t \leq 95$ seconds. For plume convection maximum heating rates see Table 14 of this report.

2) Integrated heat loads contain both aeroheating and plume convection.

TABLE 13 CONTINUED
d) DESIGN ENVIRONMENTS FOR THE LH_2 TANK ACREAGE

BODY POINT	COORDINATES		LOCATION	MAX HEATING RATE (BTU/ft^2sec)		HEAT LOAD (BTU/ft^2)	
	X_T (in)	θ_T (deg)		RI	REMTECH	RI	REMTECH
7852	1898.04	315.0	LH_2 Tank Acreage	2.40	1.79	214.8	212.9
56565	1914.24	32.5		9.89	—	494.0	—
1406	1914.65	304.0		5.39	5.47	305.3	256.7
1409	1914.65	315.0		3.07	2.97	263.5	246.7
51308	1916.00	30.9		2.08	2.17	230.9	273.3
51309	1916.00	30.9		2.24	2.36	238.9	285.8
51311	1916.00	30.9		1.57	1.63	202.8	236.8
1414	1936.79	330.2		3.51	3.74	259.6	286.2
6632	1955.30	23.5		1.11	1.96	210.9	230.4
6633	1962.78	23.5		1.39	2.03	222.4	232.3
6634	1968.39	23.5		1.75	2.08	241.1	233.7
6637	1971.66	23.5		2.96	2.11	280.4	231.6
6638	1976.81	23.5		0.81	1.07	192.5	197.5
56575	1978.74	32.5		9.39	—	460.9	—
6639	1980.31	23.5		0.93	1.07	195.2	197.4
6640	1984.05	23.5		0.91	1.07	193.4	197.3
6909	1999.54	19.0		2.32	2.27	189.4	179.1
51608	2028.00	30.9		6.05	6.50	377.2	421.0
51609	2028.00	30.9		6.38	7.07	391.6	445.7
51611	2028.00	30.9		5.02	4.80	332.6	346.6
1021	2031.65	289.5		5.26	4.65	306.9	298.4
1300	2032.00	355.0		8.42	7.86	398.5	389.1
6647	2033.00	23.5		7.62	7.47	352.0	327.9
6929	2036.45	19.0		11.14	10.60	452.7	374.2
7920	2036.46	0.0		5.88	5.49	341.5	335.5

Note: 1) Maximum heating rates pertain to the aeroheating only. Consequently in plume dominated areas between $96 \leq t \leq 126$ seconds, $\dot{q}_{max}$ is listed for $t \leq 95$ seconds. For plume convection maximum heating rates see Table 14 of this report.

2) Integrated heat loads contain both aeroheating and plume convection.

TABLE 13 CONTINUED
d) DESIGN ENVIRONMENTS FOR THE LH_2 TANK ACREAGE

BODY POINT	COORDINATES		LOCATION	MAX HEATING RATE (BTU/ft^2sec)		HEAT LOAD (BTU/ft^2)	
	X_T (in)	θ_T (deg)		RI	REMTECH	RI	REMTECH
7929	2036.46	180.0	LH_2 Tank Acreage	1.41	1.38	155.4	174.1
7925	2036.46	270.0		3.62	3.57	227.1	280.9
7922	2036.46	315.0		2.00	1.92	229.2	239.1
7921	2036.46	337.5		3.51	2.87	266.1	263.2
1041	2040.75	250.5		3.26	2.65	231.9	257.2
1023	2048.45	289.5		5.21	5.46	289.3	301.2
1043	2048.75	250.5		4.39	3.43	280.0	257.2
1025	2052.65	289.5		9.09	9.14	416.7	388.4
1205	2053.50	312.6		6.97	7.08	425.6	326.2
1303	2053.50	355.0		9.24	9.68	438.6	376.3
1046	2053.75	250.0		6.92	6.76	344.0	302.2
7930	2058.00	0.0		3.02	3.52	250.0	309.4
7939	2058.00	180.0		1.00	1.06	152.0	167.0
7937	2058.00	225.0		1.05	1.24	174.3	175.0
1054	2058.00	247.0		6.49	6.51	308.8	309.0
7935	2058.00	270.0		3.50	6.96	227.8	331.0
1032	2058.00	283.9		8.39	7.00	389.9	361.7
1211	2058.00	319.4		7.99	6.96	379.0	323.6
7931	2058.00	337.5		1.98	6.72	207.5	507.8
1307	2058.00	357.1		9.21	9.41	398.1	355.5
1309	2058.00	358.8		9.34	9.01	396.7	346.8

Note: 1) Maximum heating rates pertain to the aeroheating only. Consequently in plume dominated areas between $96 \leq t \leq 126$ seconds, $\dot{q}_{max}$ is listed for $t \leq 95$ seconds. For plume convection maximum heating rates see Table 14 of this report.

2) Integrated heat loads contain both aeroheating and plume convection.

TABLE 14: AEROHEATING AND PLUME CONVECTION MAX HEATING RATE SUMMARY FOR BODY POINT LOCATIONS $X_T \geq 1872$

Body Point	X_T	θ_T	Aeroheating* REMTECH Max Heating Rate	Aeroheating* RI Max Heating Rate	Plume Conv. RI Max Heating Rate	Method to use when 96 sec ≤ t ≤ 126 sec
7830	1872.20	0.0	2.42	1.99	3.91	Plume Convection
7839	1872.20	180.0	1.38	1.34	3.65	Plume Convection
7837	1872.20	225.0	1.30	1.38	3.65	Plume Convection
7836	1872.20	247.5	1.32	1.13	3.91	Plume Convection
7835	1872.20	270.0	1.46	3.15	3.91	Plume Convection
7834	1872.20	292.5	1.94	4.24	3.91	Aeroheating
7832	1872.20	315.0	1.85	1.75	3.91	Plume Convection
7831	1872.20	337.5	1.27	1.55	3.91	Plume Convection
7850	1898.04	0.0	1.70	2.77	3.91	Plume Convection
7859	1898.04	180.0	1.23	1.53	3.65	Plume Convection
7855	1898.04	270.0	1.88	1.98	3.65	Plume Convection
7852	1898.04	315.0	1.79	2.40	3.65	Plume Convection
1406	1914.65	304.0	5.47	5.39	3.91	Aeroheating
1409	1914.65	315.0	2.97	3.07	3.91	Plume Convection
51308	1916.00	30.9	2.17	2.08	3.91	Plume Convection
51309	1916.00	30.9	2.36	2.24	3.91	Plume Convection
51311	1916.00	30.9	1.63	1.57	3.91	Plume Convection
1414	1936.79	330.2	3.74	3.51	3.91	Plume Convection
6632	1955.30	23.5	1.96	1.11	3.91	Plume Convection
6633	1962.78	23.5	2.03	1.39	3.91	Plume Convection
6634	1968.39	23.5	2.08	1.75	3.91	Plume Convection
6637	1971.66	23.5	2.11	2.96	3.91	Plume Convection
6638	1976.81	23.5	1.07	0.81	3.91	Plume Convection
6639	1980.31	23.5	1.07	0.93	3.91	Plume Convection
6640	1984.05	23.5	1.07	0.91	3.91	Plume Convection
6909	1999.54	19.0	2.27	2.32	—	Aeroheating
51608	2028.00	30.9	6.50	6.05	3.91	Plume Convection

TABLE 14 CONC:
AEROHEATING AND PLUME CONVECTION MAX HEATING RATE SUMMARY FOR BODY POINT LOCATIONS $X_T \geq 1872$

Body Point	X_T	θ_T	Aeroheating* REMTECH Max Heating Rate	Aeroheating* RI Max Heating Rate	Plume Conv. RI Max Heating Rate	Method to use when 96 sec ≤ t ≤ 126 sec
51609	2028.00	30.9	7.07	6.38	3.91	Plume Convection
51611	2028.00	30.9	4.80	5.02	3.91	Plume Convection
1021	2031.65	289.5	4.65	5.26	3.91	Plume Convection
1300	2032.00	355.0	7.86	8.42	3.91	Plume Convection
6647	2033.00	23.5	7.47	7.62	3.91	Plume Convection
6929	2036.45	19.0	10.60	11.14	3.91	Plume Convection
7920	2036.46	0.0	5.49	5.88	3.91	Plume Convection
7929	2036.46	180.0	1.38	1.41	3.65	Plume Convection
7925	2036.46	270.0	3.57	3.62	3.91	Plume Convection
7922	2036.46	315.0	1.92	2.00	3.91	Plume Convection
7921	2036.46	337.5	2.87	3.51	3.91	Plume Convection
1041	2040.76	250.5	2.65	3.26	3.91	Plume Convection
1023	2048.45	289.5	5.46	5.21	3.91	Plume Convection
1043	2048.75	250.5	3.43	4.39	3.91	Plume Convection
1025	2052.65	289.5	9.14	9.09	3.91	Plume Convection
1205	2053.50	312.6	7.08	6.97	3.91	Plume Convection
1303	2053.50	355.0	9.68	9.24	3.91	Plume Convection
1046	2053.75	250.5	6.76	6.92	3.91	Plume Convection
7930	2058.00	0.0	3.52	3.02	3.91	Plume Convection
7939	2058.00	180.0	1.06	1.00	3.65	Plume Convection
7937	2058.00	225.0	1.24	1.05	3.65	Plume Convection
1054	2058.00	247.0	6.51	6.49	3.91	Plume Convection
7935	2058.00	270.0	6.96	3.50	3.91	Plume Convection
1032	2058.00	283.9	7.00	8.39	3.91	Plume Convection
1211	2058.00	319.4	6.96	7.99	3.91	Plume Convection
7931	2058.00	337.5	6.72	1.98	3.91	Plume Convection
1307	2058.00	357.1	9.41	9.21	3.91	Plume Convection
1309	2058.00	358.8	9.01	9.34	3.91	Plume Convection

* Note: The aeroheating max. heating rates are for time ≤ 95 seconds.

Table 15: Body Points at which Environments did not Favorably Compare Between RI IVBC-3 and REMTECH

B.P.	XT (inches)	ΘT (deg.)	LOCATION
70500	324.24	0.0	40° Cone
70550		180.0	
70575		270.0	
70600	345.0	0.0	
70650		180.0	
70675		270.0	
71363	513.60	225.0	LO2 Tank
71369		247.5	
71381		292.5	
71388		315.0	
71394		337.5	
1100	1111.85	343.0	Intertank
1107	1111.85	348.0	
6427	1102.62	29.0	
7302	884.85	315.0	
7324	929.10	292.5	
7352	973.40	315.0	
7355	961.20	270.0	
7364	1006.70	292.5	
7385	1038.00	270.0	
7386	1025.80	247.5	
7404	1069.40	292.5	
7405		270.0	
7406		247.5	
7425	1102.62	270.0	
1401	1822.4	309.4	LH2 Tank
6582	1127.6	23.5	
7694	1615.7	292.5	
7931	2058.0	337.5	
7935		270.0	

Table 16: Overview of Net Spray Application Tolerances

Surface Geometry	CPR Tolerance*
Flat	± 0.25
Cylinder	± 0.25
LO2 Fwd Ogive	± 0.38
LO2 Aft Ogive	± 0.25
Intertank	
Skin/Stringer	+ 0.38/- 1.00
Thrust Panel	+ 0.38/- 0.70
Intertank (Smooth)	
CPR-488 over BX -250	± 0.25
Domes:	
LH2 Aft Dome	± 0.25
LH2 Fwd Dome	± 0.25
Aft Dome	+ 0.50/- 0.25

* Source: Ref. 12